



Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project EIS Coastal Processes and Hydrodynamics

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Abbreviations

ADCP	Acoustic Doppler Current Profiler
AHD	Australian Height Datum
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
BPAR	Benthic Photosynthetically Active Radiation
BUF	Barge Unloading Facility
CFSR	Climate Forecast System Reanalysis
CSD	Cutter Suction Dredger
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DES	Department of Environment and Science
DMPA	Dredge Material Placement Area
DSITI	Department of Science, Information Technology and Innovation
EHP	Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GPCL	Gladstone Ports Corporation Limited
HAT	Highest Astronomic Tide
IPCC	Intergovernmental Panel on Climate Change
LAT	Lowest Astronomic Tide
MPI	Maximum Potential Intensity
MSE	Mean Squared Error
MSQ	Maritime Safety Queensland
NCEP	National Centers for Environmental Prediction
NTC	National Tidal Centre
NTU	Nephelometric Turbidity Units
PAR	Photosynthetically Active Radiation
RCPs	Representative Concentration Pathways
SLR	Sea Level Rise
TSHD	Trailing Suction Hopper Dredger
TSS	Total Suspended Solids
WB	Western Basin
WBE	Western Basin Expansion

Contents

Glossary

Accretion	Build up of material, e.g., sand as a result of coastal or fluvial processes
Bed Shear Stress	The force per unit area exerted by a fluid on the bed
Bioavailable	Available for biological processes
EM3	Mixing zone model used to predict and assess impacts of continuous point source discharge to surface water
Ebb tide	The outgoing tide
Far field	Area of mixing region dominated by the ambient turbulent diffusion, i.e. ambient velocity and channel geometry
Flood tide	The incoming tide
HYCOM model	A data-assimilative hybrid isopycnal-sigma-pressure coordinate ocean model
NCEP CFSR model	A global, high-resolution coupled atmosphere–ocean–land surface–sea ice data-assimilative model
Near field	Area of mixing region dominated by the initial momentum of discharge
Neap tide	The tides which occur around the first and last quarter of the moon, when the difference between high and low water is lower than average
Offshore area	Areas located outside the Port and away from the shoreline
Outer Harbour (Gladstone)	Areas outside the protection of Facing Island (i.e. to the south of Gatcombe Head)
Resuspension	Sediment that was previously deposited on the seabed is entrained back into suspension in the water column
Smagorinsky model	A turbulence model that assumes that the energy production and dissipation at small scales are in equilibrium
Spring tide	The tides which occur around the new or full moon, when the difference between high and low water is higher than average
SWAN	3 rd generation spectral wave modelling software
TUFLOW FV	Hydrodynamic and advection-dispersion modelling software
Turbidity	A measure of the degree to which the water loses its transparency due to the presence of suspended particulates

1 Overview

1.1 Background

Gladstone Ports Corporation Limited (GPCL) is seeking to duplicate the existing Gatcombe and Golding Cutting bypass shipping channels to accommodate a predicted increase in shipping traffic as a result of ongoing industrial growth within the Port. The duplicate channels are proposed to be deepened adjacent to the existing shipping channel, facilitating two-way shipping traffic from the outer harbour.

The key relevant components of the Port of Gladstone Gatcombe and Golding Cutting Channel Duplication (the Project) include:

- Construction of a barge unloading facility (BUF) and the Western Basin Expansion (WBE) reclamation area bund walls prior to dredging commencing;
- Initial dredging of approximately 0.25 million cubic metres (10^6 m^3) of seabed material (including dredging tolerance) to establish a 2.3 kilometres (km) long access channel to -7 metres (m) Lowest Astronomic Tide (LAT) to allow barges to transport dredged material from the Gatcombe and Golding Cutting shipping channels to the BUF;
- Dredging approximately $12.6 \times 10^6 \text{ m}^3$ (12.6 million cubic metres) of seabed material (including dredging tolerance) to permanently duplicate the Gatcombe and Golding Cutting shipping channels. The estimated total Project dredging volume, including initial dredging works, is $12.85 \times 10^6 \text{ m}^3$ and the length of the channel to be dredged is approximately 15km;
- Preferred dredging methodology involves utilising a TSHD which loads the dredged material from the Gatcombe and Golding Cutting shipping channels into barges (four barges will be working in cycles for the entire dredging operations) which will transport the material to the BUF to be unloaded using large excavators into trucks for placement within the existing Western Basin (WB) and WBE reclamation areas; and
- Dredged material placement within the WB and WBE reclamation areas.

Maintenance dredging within duplicated channels and barge access channel.

This report forms part of the Project Environmental Impact Statement (EIS) and Additional Information on the EIS (AEIS), which describes the potential environmental impacts of the Project. The proposed initial dredging works, channel duplication, BUF, WBE reclamation area and the Great Barrier Reef Marine Park (GBRMP) boundary are shown in Figure 1-1.

1.2 Purpose and Objectives

The purpose and objectives of this report are:

- To describe the existing coastal processes and hydrodynamics of the Port of Gladstone using data collected and supplied by reliable sources as well as a suite of calibrated hydrodynamic, wave and sediment transport models; and
- To assess potential impacts of the proposed development on the hydrodynamics and coastal processes within the study area. These potential impacts include changes to hydrodynamics,

Overview

wave climate, shoreline sediment transport, siltation, suspended sediment concentrations and reduction in light received by seagrass, corals and other marine substrates.

In order to carry out impact assessments, the numerical models must be able to accurately represent the key physical processes of the existing Port environment. The modelling must also be undertaken in accordance with the Great Barrier Reef Marine Park Authority (GBRMPA) Hydrodynamic Modelling Guidelines (GBRMPA 2012), which are provided in Appendix A of this report. Section 2.5 of this report describes how the models have been calibrated and validated using appropriate data sets in accordance with the GBRMPA Guidelines and the EIS Terms of Reference and Guidelines.

Data sets were collected from June 2014 to July 2015 and included wave parameters, turbidity, water level and water velocity at a number of locations in the vicinity of proposed Project work sites. The hydrodynamic and sediment transport processes within the Port are modelled using a numerical TUFLOW FV model. Wave processes are modelled using a 3rd generation SWAN spectral wave model (Delft University of Technology 2006).

Overview

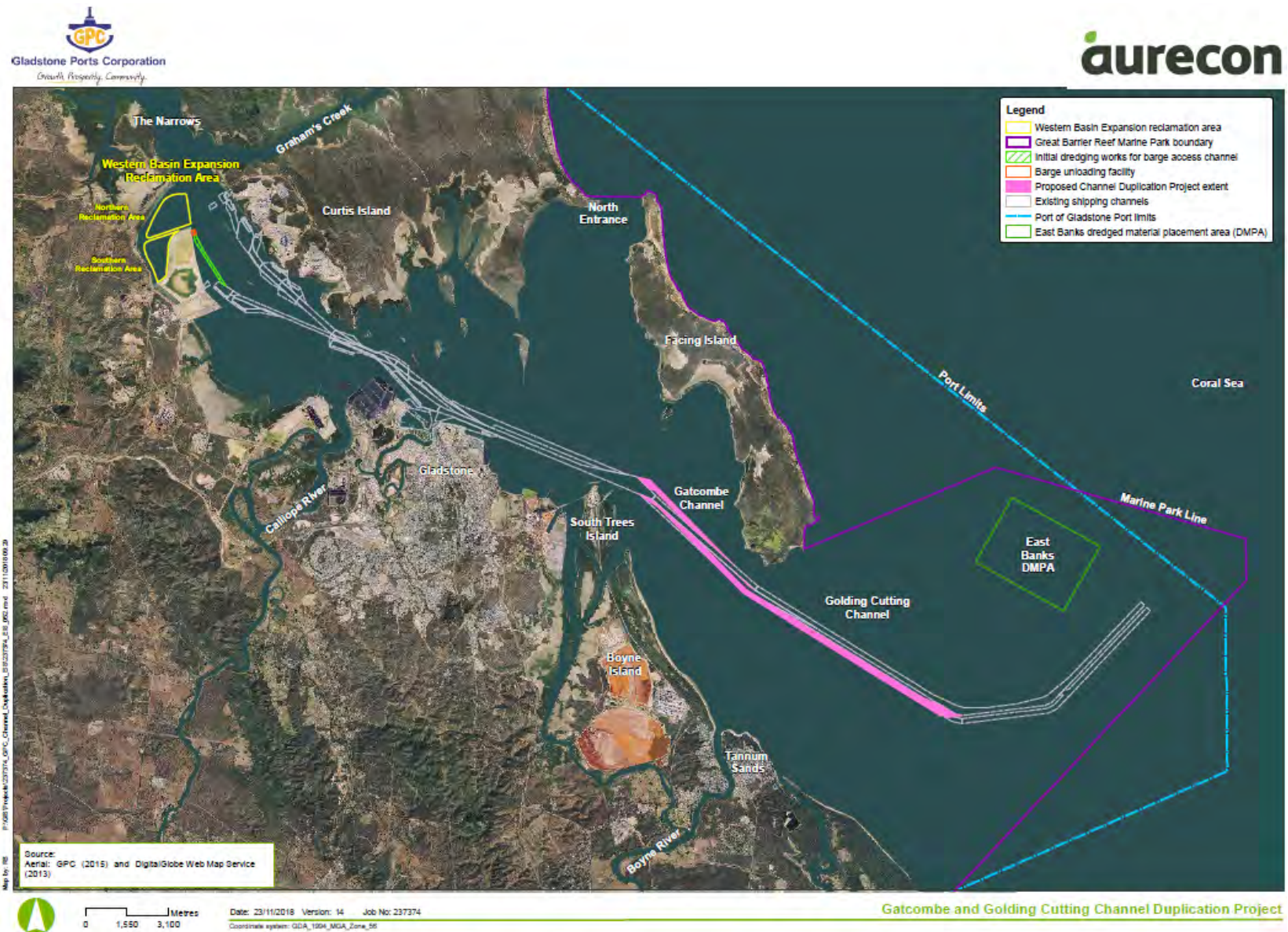


Figure 1-1 Locality Plan

2 Model Setup and Calibration

2.1 Hydrodynamic Model Description

2.1.1 Numerical Modelling Software

The hydrodynamic modelling component of these assessments uses the TUFLOW FV software, which is developed and distributed by BMT WBM (www.tuflow.com). TUFLOW FV is a numerical hydrodynamic model for the three-dimensional (3D) Non-Linear Shallow Water Equations (NLSWE). The model is suitable for solving a wide range of hydrodynamic systems ranging in scale from open channels and floodplains, through estuaries to coasts and oceans.

The Finite-Volume (FV) numerical scheme employed by TUFLOW FV is capable of solving the NLSWE on both structured rectilinear grids and unstructured meshes comprised of triangular and quadrilateral elements. The flexible mesh allows for seamless boundary fitting along complex coastlines or open channels as well as accurately and efficiently representing complex bathymetries with a minimum number of computational elements. The flexible mesh capability is particularly efficient at resolving a range of scales in a single model without requiring multiple domain nesting. Further details regarding the numerical scheme employed by TUFLOW FV are provided in the TUFLOW FV Science Manual (BMT WBM 2015c).

The TUFLOW FV model is configured as a 3D model with baroclinic coupling from both salinity and temperature variations. Atmospheric heat fluxes and water column heat dynamics are simulated internally within TUFLOW FV. The inclusion of baroclinic pressure gradient terms in the solution scheme allows for the development of a stratified water column, although in Port Curtis and the outer harbour this is rarely observed due to the mixing associated with the high energy tidal environment.

A hybrid z-coordinate vertical grid configuration with three surface 'sigma' layers is used for the hydrodynamic model. The vertical grid has 11 layers representing the top 10 m of the water column, 13 layers between depths of 10 m and 50 m, and five layers between depths of 50 m and 500 m.

The General Ocean Turbulence Model (www.gotm.net) is linked with TUFLOW FV to control vertical mixing of both momentum and sediment, employing a 2-equation k-omega turbulence scheme. A Smagorinsky model is used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

2.1.2 Model Domain and Mesh

The domain of the TUFLOW FV hydrodynamic model used in this study is larger than previous Gladstone harbour models. The model domain encompasses 32,000 km², from Sandy Cape in the south to Cape Manifold in the north, which is large enough to accurately represent the full extent of Project-related suspended sediment plumes within the GBRMP and Great Barrier Reef World Heritage Area. The expanded TUFLOW FV model mesh is presented in Figure 2-1 and Figure 2-2.

2.1.3 Bathymetric Data

Bathymetric data in the vicinity of the Port of Gladstone was sourced from existing Digital Elevation Models developed by BMT WBM. The bathymetry is sourced from a large number of datasets acquired over many years.

- Detailed hydrographic survey data of the dredged channels, swing basins and berths as provided by MSQ and GPC, together with the progressive inclusion of ongoing surveys to ensure that the model bed levels match the actual bathymetric configuration at the time of the simulation period (updated to November 2018);
- Detailed hydrographic survey data of broad areas of the Port, from MSQ and GPC; and
- Hydrographic survey data and outlines of the edges of the shoreline, mangroves and salt pans used in producing Boating Safety Charts of the area, as provided by MSQ.

Bathymetric data offshore (30m horizontal resolution) was sourced from Project 3DGBR: a high-resolution depth model for the Great Barrier Reef and Coral Sea (Beaman 2018). Where this data interfaced with the local Digital Elevation Model, the two datasets were checked for consistency and smoothed where necessary (see Figure 2-3).

The bathymetry of the model was updated with recent survey data from GPC which included the dredging undertaken for the liquefied natural gas (LNG) projects on Curtis Island and the first stage of the Wiggins Island Coal Terminal (WICT) Project. The model bathymetry is therefore an accurate representation of the actual bathymetry of the Port during the data collection period. The adopted model bathymetry is illustrated in Figure 2-4 and Figure 2-5.

It is acknowledged that the model bathymetry may need to be updated for any additional assessment work prior to dredging commencing, depending on the final timing of the Project.

2.2 Wave Model Description

A wave model was developed in order to simulate the wave-related stresses (particularly bed shear stresses) that have an influence on hydrodynamics, sediment re-suspension and sediment transport. The SWAN (Delft University of Technology 2006) numerical model is used for this purpose. SWAN is a third-generation spectral wave model, which is capable of simulating the generation of waves by wind, dissipation by white-capping, depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. The SWAN wave model includes a coarse regional-scale grid (~1,000 m resolution), a nested medium-scale grid (~250 m resolution) and a nested local-scale grid (~50 m resolution). The domains of the SWAN grids are shown in Figure 2-6.

2.3 Model Boundary Conditions

2.3.1 Tide

Tidal boundary conditions along the open ocean boundary of the model were sourced from a larger 2D TUFLOW FV hydrodynamic model of the Coral Sea, also developed by BMT WBM. The Coral Sea tide model boundary conditions were generated using tidal constituents supplied by

the Bureau of Meteorology (BoM), National Tide Centre (NTC), derived from the Australian Regional Tide Model (5-minute spatial resolution).

2.3.2 Oceanic Currents

Regional current forcing (residual water level, current magnitude and direction), and profiles of temperature and salinity were also applied on the open model boundaries of the model. These were derived from the ocean general circulation model, HYCOM (hycom.org) and varied both in space (longitude, latitude and elevation) and time. The HYCOM model has a spatial resolution of approximately 8 km and a temporal resolution of 24 hours. The water level specified on the model boundary was a linear superposition of the HYCOM water level and the tidal water level. At each time step the velocity profiles at the open ocean boundary were specified as a superposition of the HYCOM velocity profile and the depth-averaged tidal current and then relaxed barotropically using an active Flather (1976) condition. This minimises the reflection of outward propagating barotropic waves at the model open boundaries (allows for the over-specification of the boundary conditions).

2.3.3 Wind

Wind velocity boundary conditions for the calibration period were obtained from global NCEP CFSR model reanalyses (NOAA 2012). The CFSR model has a spatial resolution of 0.2 degrees in the study area which is high enough to minimise errors arising from interpolation in the vicinity of the shoreline. The temporal resolution of the CFSR outputs is one hour. This wind field was applied to both the hydrodynamic and wave models.

2.3.4 Atmospheric Forcing

Boundary condition data, including air temperature, long and short wave radiation, precipitation and relative humidity were also obtained from global NCEP CFSR model reanalyses (NOAA 2012). These model outputs had the same spatial and temporal resolution as the wind outputs and were applied to the hydrodynamic model only.

2.3.5 Freshwater Inflows

There are a number of tidal tributaries incorporated in the model, including the Calliope and Boyne Rivers. The normal day to day fluvial component of flow within these river systems is generally insignificant in relation to the tidal fluxes through Port Curtis, except during major flood events. Freshwater inputs for the model calibration period (July 2014 to June 2015) were obtained from a hydrologic catchment model developed by BMT WBM for the Port Curtis region. Additional data for Awoonga Dam spillway flows was sourced from the Gladstone Area Water Board.

The impact assessment simulations were undertaken with freshwater inputs corresponding to the chosen simulation period, which are representative of 'typical' meteorological conditions. The sediment fluxes associated with these freshwater flows were also included in the ambient sediment dynamics modelling (and calibration process).

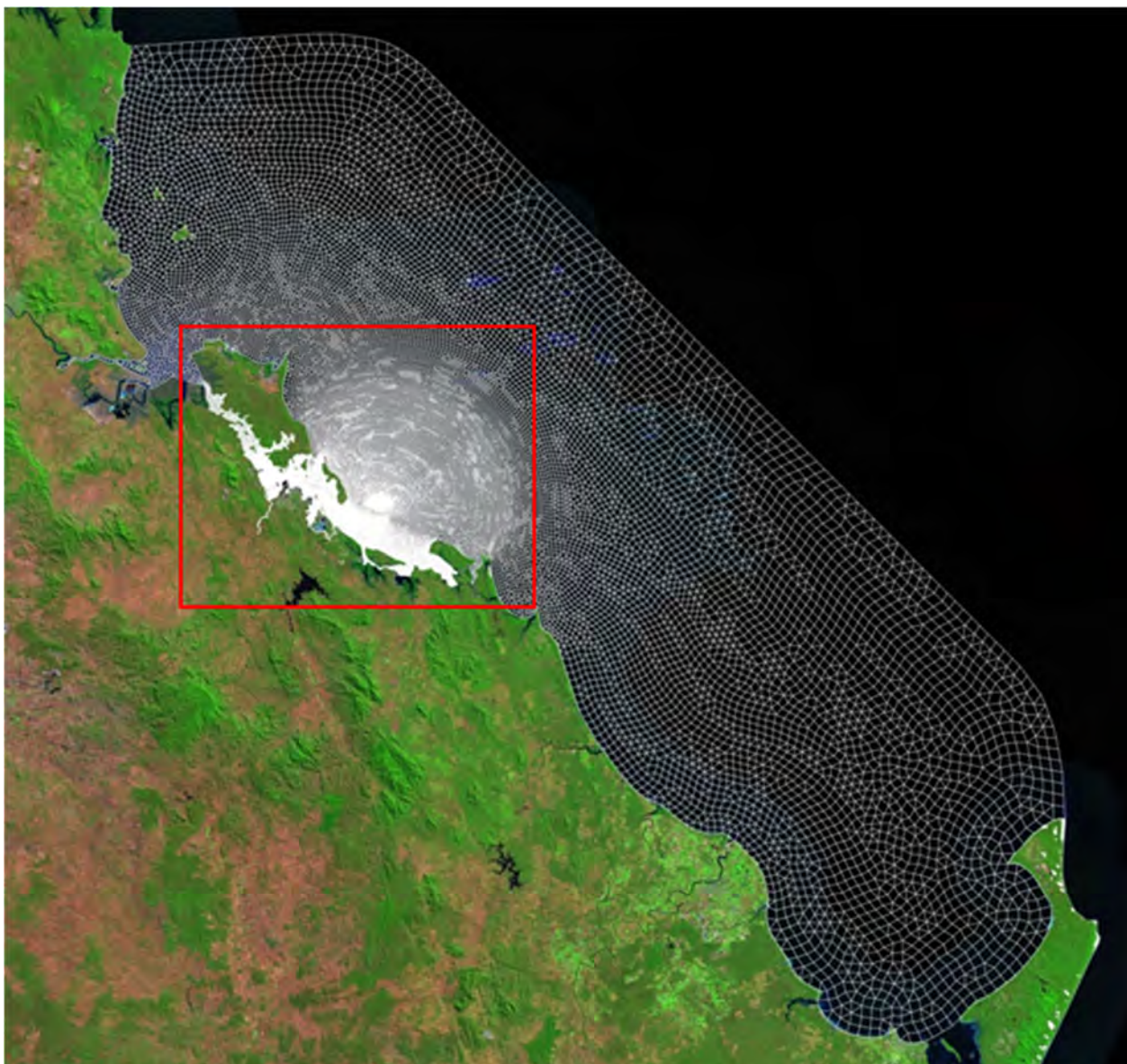


Figure 2-1 TUFLOW FV Model Mesh – Whole Model Domain

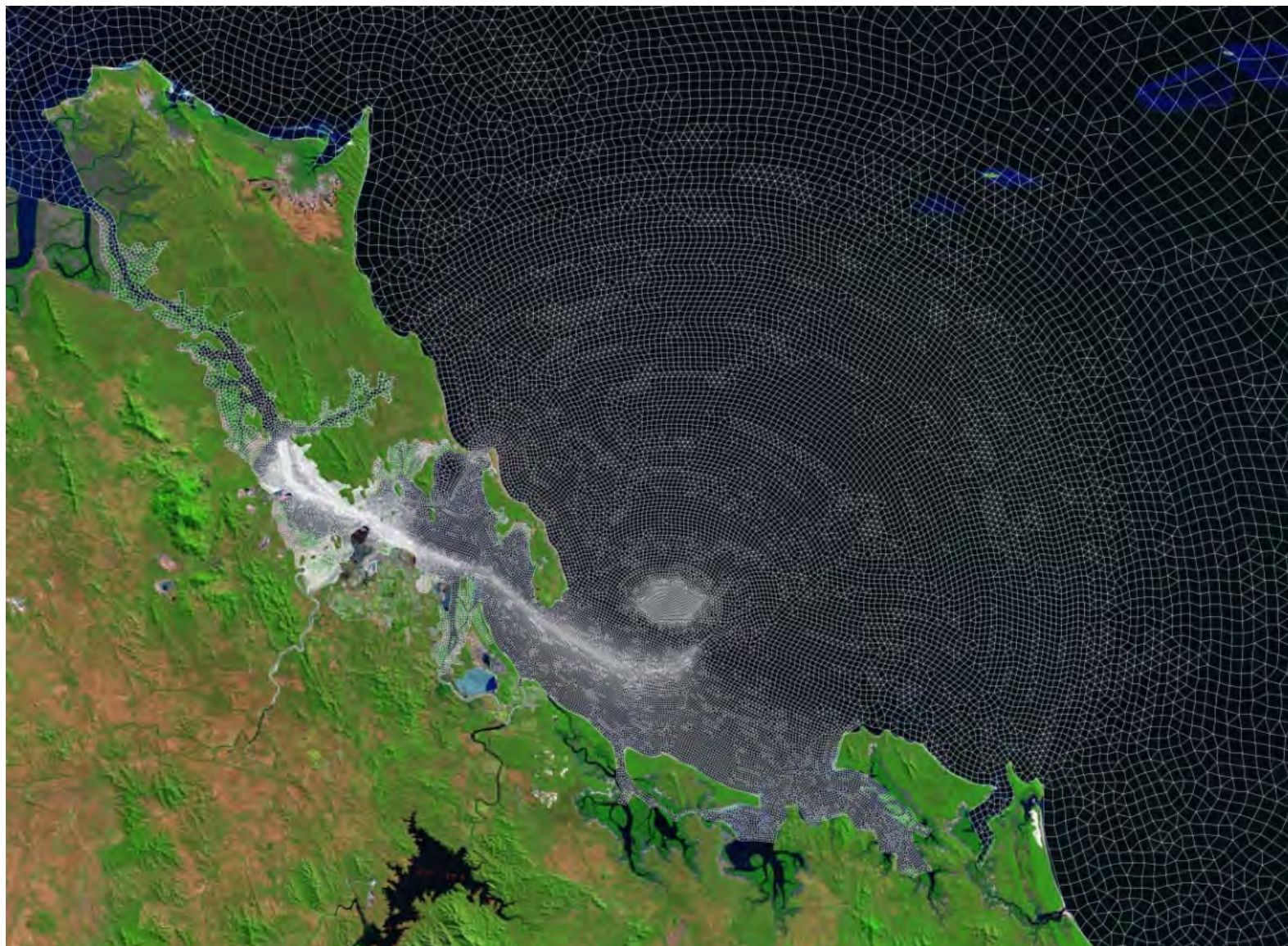


Figure 2-2 TUFLOW FV Model Mesh – Local Scale (Red Boxed Area in Figure 2-1)

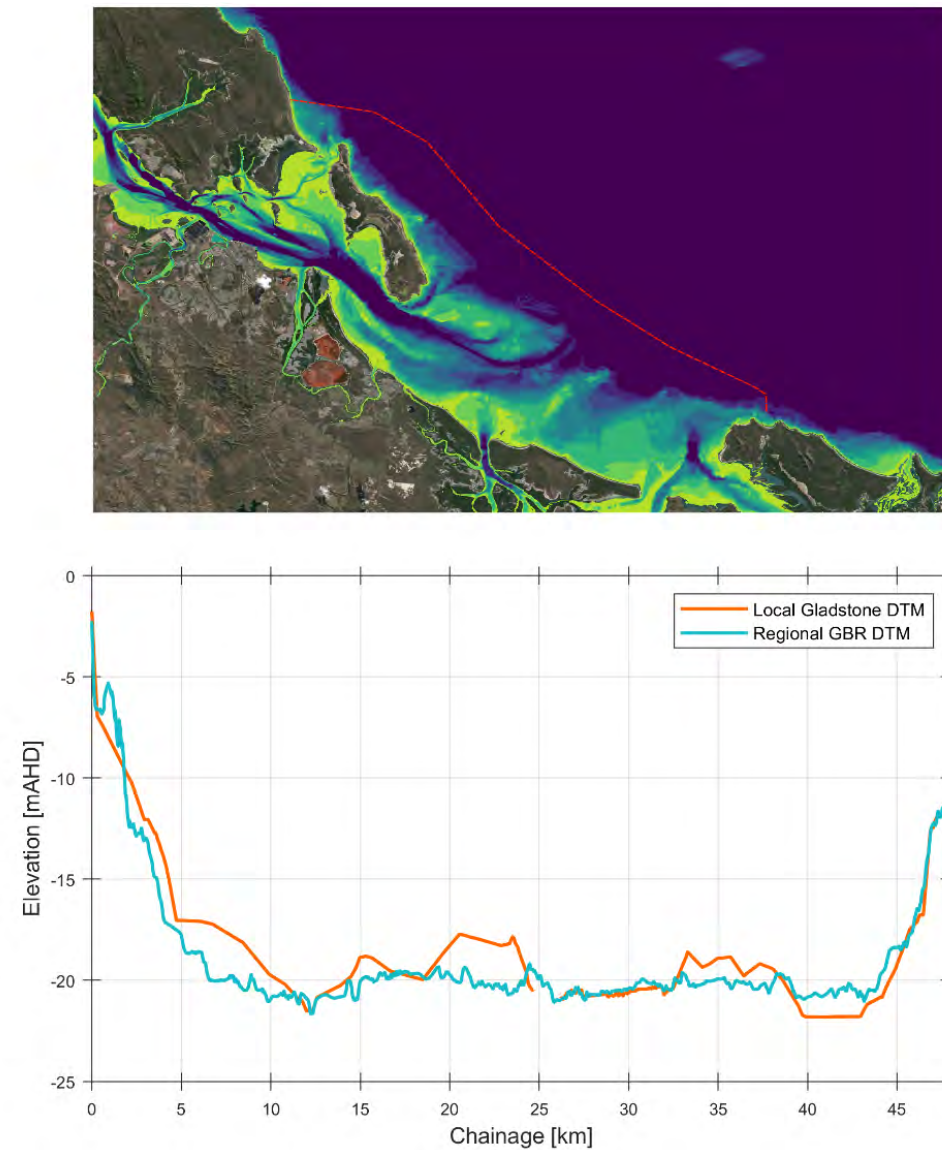


Figure 2-3 Comparison at Interface of Regional and Local Bathymetric Datasets

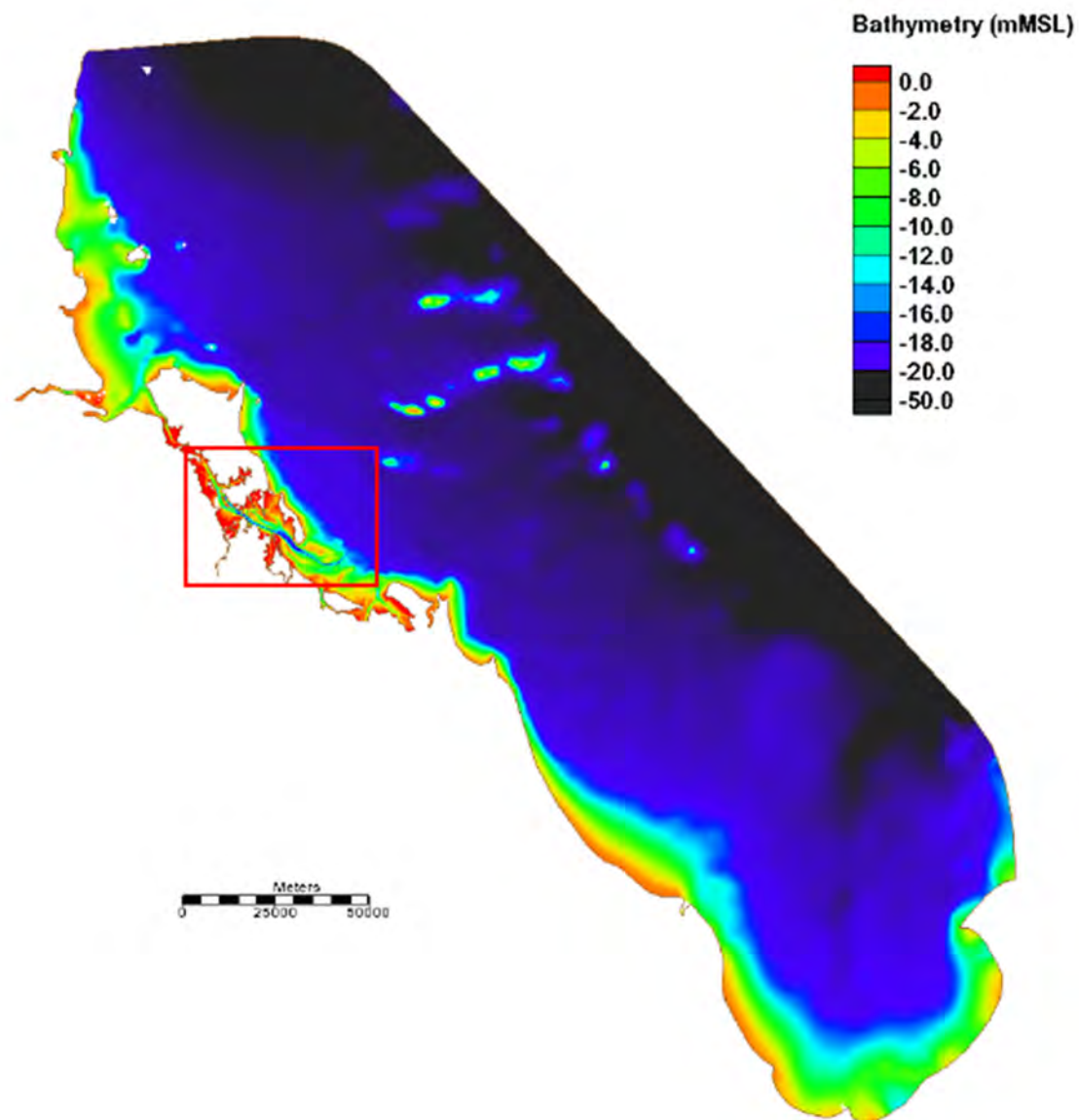


Figure 2-4 Model Bathymetry – Whole Model Domain

Model Setup and Calibration

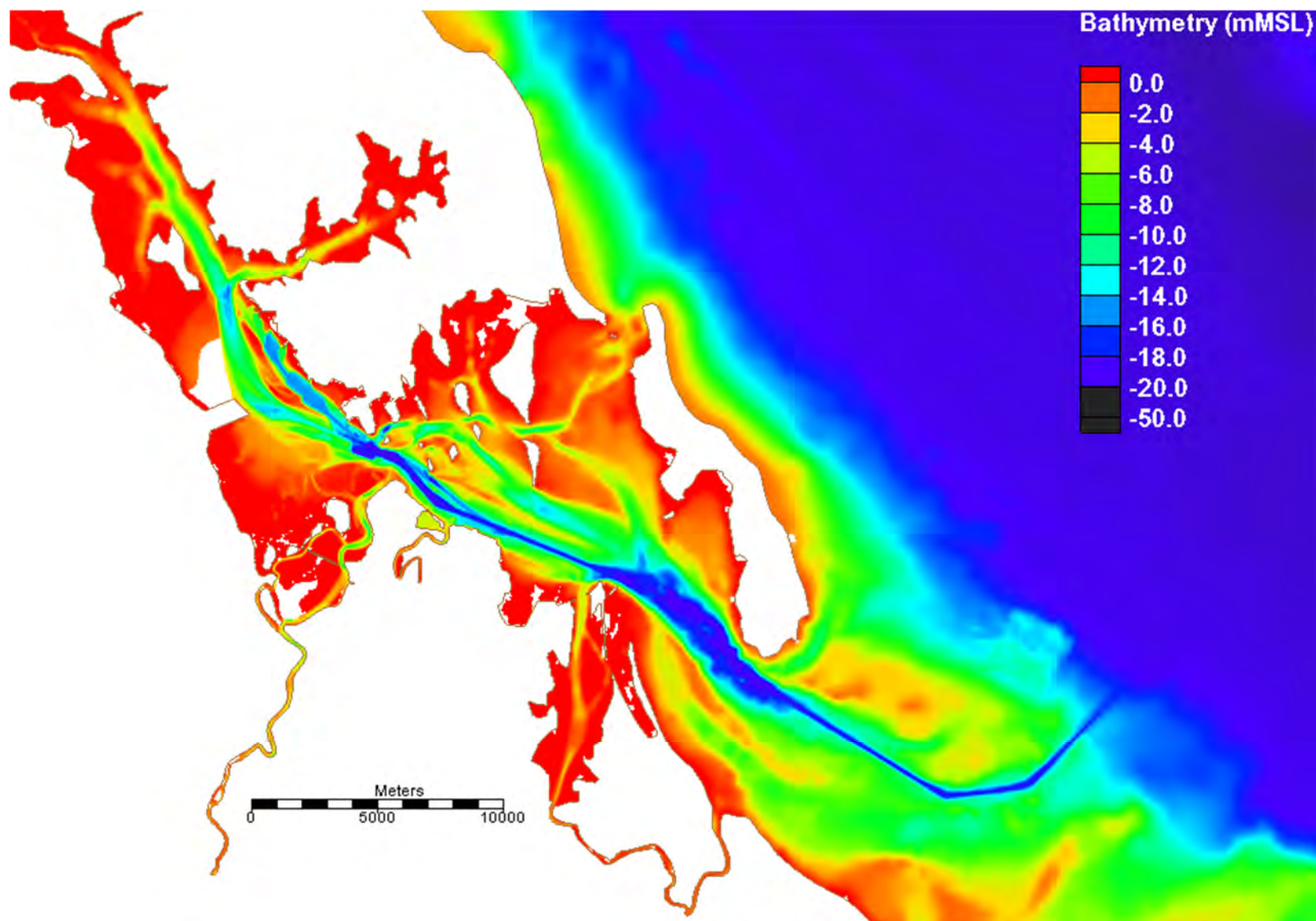


Figure 2-5 Model Bathymetry – Local Scale (Red Boxed Area in Figure 2-4)

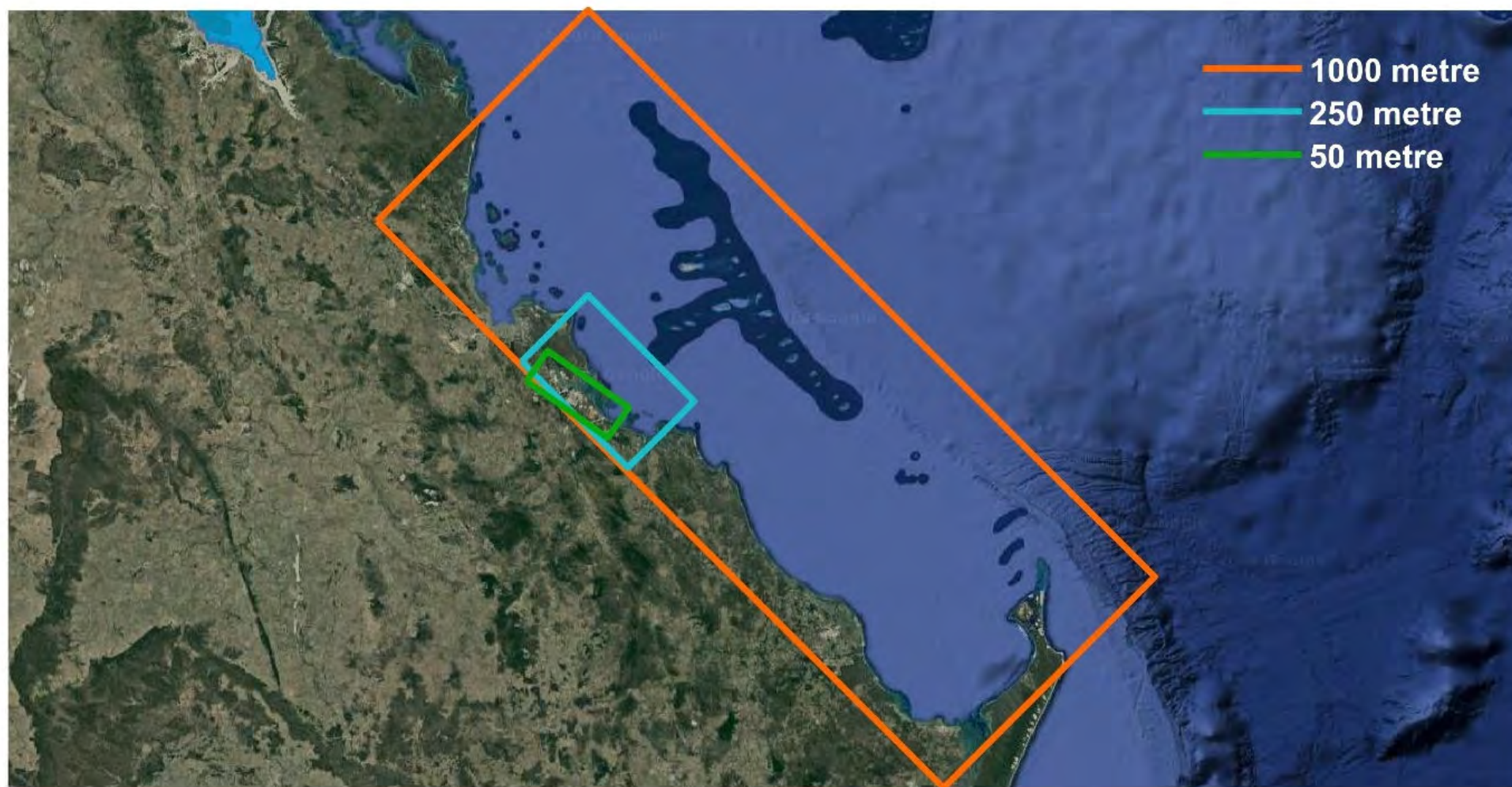


Figure 2-6 SWAN Model Domains

2.4 Data Collection

2.4.1 Water Level, Tidal Currents and Water Quality

An extensive data collection campaign has been undertaken in accordance with the GBRMPA Hydrodynamic Modelling Guidelines (refer Appendix A, GBRMPA 2012). The data collection program was reviewed by key government agencies before implementation. The data collection program and comments from GBRMPA are provided in Appendix B. The data collected included turbidity, temperature, salinity, wave height, wave period, wave direction, water velocity and water levels. The locations of the instruments deployed are shown in Figure 2-7, and the coordinates and data types collected are provided in Table 2-1. Also included in Table 2-1 and Figure 2-7 are permanent wind, tide and wave recorders operated by the BoM and the Queensland Government.

Table 2-1 Instrument Locations and Data Types

Instrument	Latitude	Longitude	Data Type
P2B/WB50 (surface)	-23.8048	151.209	Water quality
P5/MH30 (surface)	-23.7838	151.306	Water quality
CD1 (surface and benthic)	-23.9578	151.502	Water quality, BPAR
CD2 (surface and benthic)	-23.8669	151.406	Water quality, BPAR
CD3 (surface and benthic)	-23.9165	151.359	Water quality, BPAR
CD4 (surface and benthic)	-23.7711	151.377	Water quality, BPAR
CD5 (surface and benthic)	-23.8364	151.453	Water quality, BPAR
QE3 (surface)	-23.7158	151.141	Water quality
Gladstone Waverider Buoy (DES)	-23.8956	151.502	Wave data
Gladstone Radar (Wind) (BoM)	-23.8553	151.263	Wind data
Auckland Point (Tide Gauge) (MSQ)	-23.831	151.255	Tide data
South Trees (Tide Gauge) (DES)	-23.8516	151.31	Tide data
ADCP 1	-23.8608	151.484	Water velocity, waves, turbidity
ADCP 2	-23.9273	151.428	Water velocity, waves, turbidity
ADCP 3	-23.861	151.343	Water velocity, waves, turbidity
ADCP 4	-23.8954	151.341	Water velocity, waves, turbidity
ADCP 5	-23.8441	151.293	Water velocity, waves, turbidity
ADCP 6	-23.8811	151.392	Water velocity, waves, turbidity

Table notes:

BPAR Benthic Photosynthetically Active Radiation
DES Department of Environment and Science
MSQ Maritime Safety Queensland

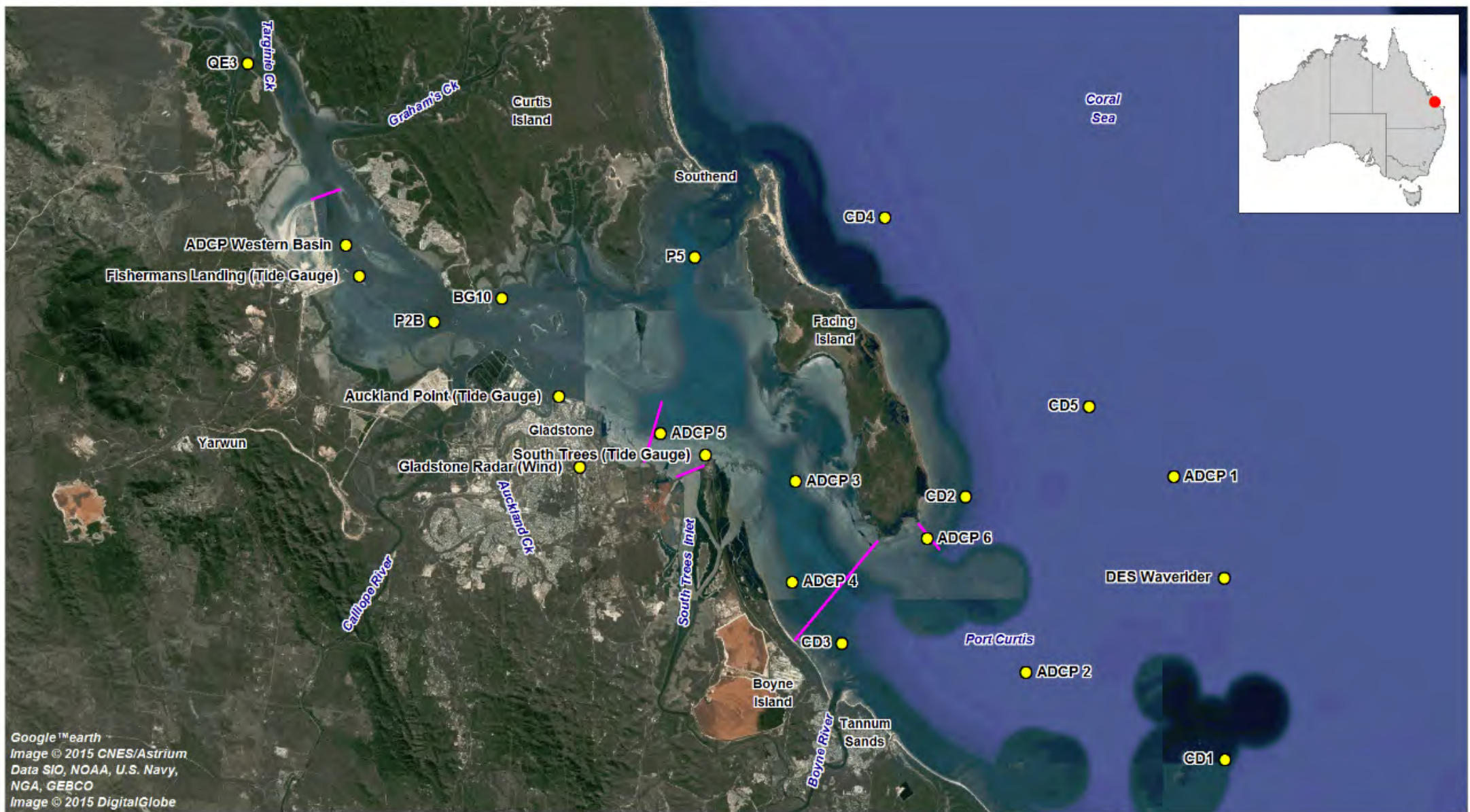
Bottom-mounted Acoustic Doppler Current Profilers (ADCPs) were deployed at six locations shown in Figure 2-7. At sites ADCP1 and ADCP4 the current and wave recording was continuous for 12 months, while at the other four sites seasonal data was collected (three months at each site on two occasions over the 12-month period). Turbidity data was collected at these same ADCP locations (approximately 1 metre above the seabed), and also at other locations shown in Figure 2-7. The data collection campaign finished in July 2015 and model validation has been carried out using the full 12-month dataset as agreed with government agencies.

In addition, the tidal current magnitudes across five transects were measured during a single spring tidal cycle using a boat mounted ADCP in June 2015. The locations of the five transects are shown in Figure 2-7.

2.4.2 Wind and Wave Data from External Sources

The calibration of the TUFLOW FV model was undertaken using data collected from 25 June 2014 to 1 July 2015. The wind and wave roses for this period are shown in Figure 2-8. The wind rose is based on data from the BoM for the 'Gladstone Radar' station. The wave rose is derived from data from the Gladstone Waverider Buoy which is operated by the Queensland Government's Department of Environment and Science (DES). The long term (~5 year) wind and wave roses are provided in Figure 3-4 for comparison purposes. The wind and wave conditions during the calibration period were generally consistent with the long term conditions, though with a slightly larger percentage frequency of northeast winds and a slightly smaller percentage frequency of southeast winds.

A comparison of the BoM 'Gladstone Radar' data and the NCEP CFSR model output is provided in Figure 2-9. The model output (used as a boundary condition for the TUFLOW FV and SWAN models) is in close agreement with the measured wind speed and direction at that location. The CFSR model output does slightly underestimate the diurnal variation in magnitude and direction, which may be due to local sea breeze effects. Note that the BoM wind speeds are 10-minute averages, while the CFSR model output has a temporal resolution of 1 hour, with no averaging.



LEGEND

● Instrument Location

— ADCP Transect

Title:

Measurement Locations

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.



0km 5 10
Approx. Scale

Figure:

2-7

Rev:

A



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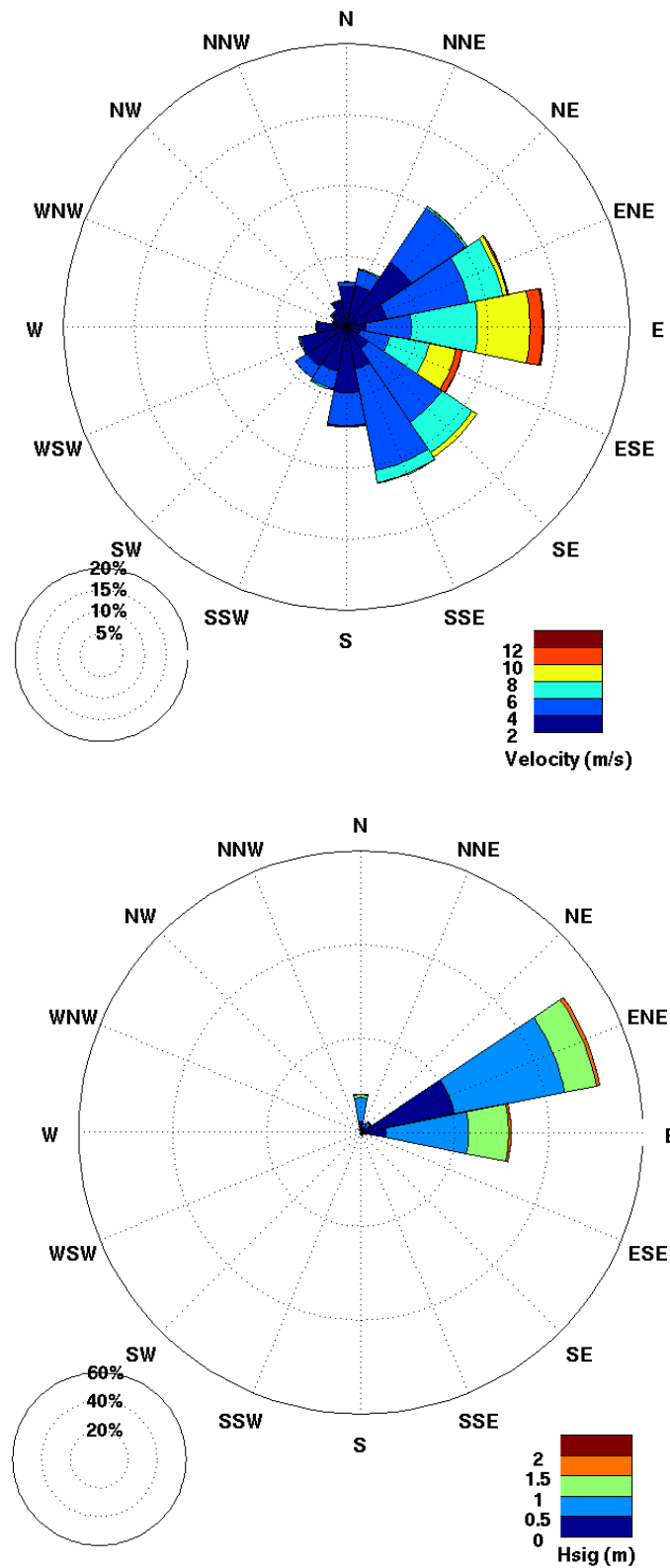


Figure 2-8 Wind Rose at Gladstone Radar (Top) and Wave Rose at Gladstone Waverider Buoy (Bottom) for the Calibration Period (1/7/2014 to 1/7/2015)

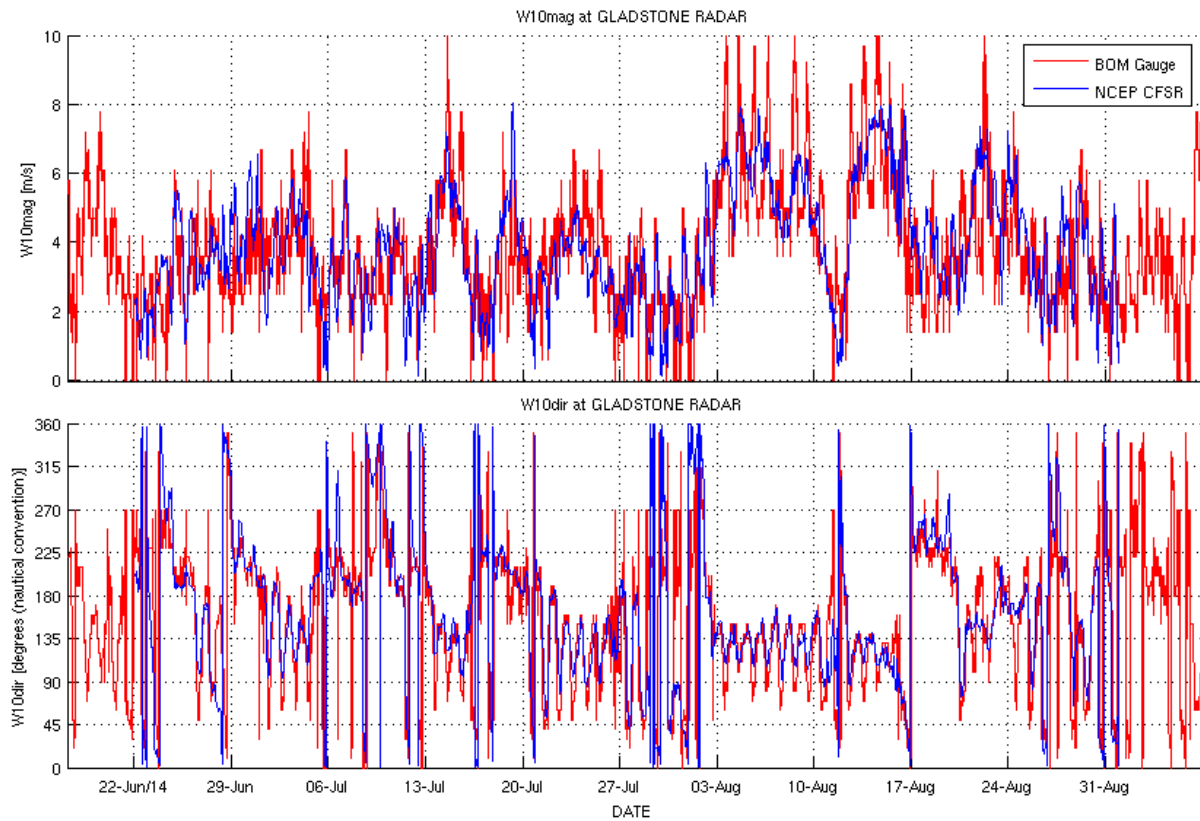


Figure 2-9 Comparison of 10m Wind Speed (Top) and Wind Direction (Bottom) for the NCEP CFSR Model Output (Blue Line) and the Bureau of Meteorology Gauge (Red) at Gladstone Radar
Mean Squared Error (MSE) for W10mag = 1.715

2.5 Model Calibration and Validation

2.5.1 Hydrodynamic and Wave Model Calibration

The 3D TUFLOW FV model was run in 3D mode for the period 25 June 2014 to 1 July 2015 using a bathymetric configuration that matched the harbour geometry at that time (refer Figure 2-5).

Calibration was undertaken on the period spanning 25 June to 31 December 2015, using instruments deployed at various locations in Port Curtis (shown in Figure 2-7). The following six months of recordings were used to validate the model. As part of the calibration process, the specified roughness of each material type in the model was adjusted. The Nikuradse roughness numbers adopted for each material type are shown in Table 2-2.

Table 2-2 Nikuradse 'ks' Roughness Numbers

Material Type	Nikuradse 'ks'
Channels	0.02
Shallows / Intertidal Flats	0.02
Mangroves	0.5

The modelled and recorded water levels for part of the modelling period at the tide gauges at Auckland Point (MSQ) and South Trees (DES) are shown in Figure 2-10. The full set of water level validation plots are provided in Appendix C. The modelled and measured water levels at each of the ADCP locations are shown in Figure 2-11 to Figure 2-16. Agreement between the modelled and measured water levels is acceptable, although the model does underestimate the tidal range during spring tides on some occasions. Where discrepancies exist they are likely due to the limitations of using global model hindcasts for the model boundary conditions rather than locally recorded data. A comparison of tidal planes estimated from the model output with the published tidal planes at two locations is presented in Table 2-3.

Table 2-3 Comparison of Modelled Tidal Planes with Published Tidal Planes

Tidal Plane (m LAT)	Fishermans Landing		Auckland Point	
	Modelled	Published	Modelled	Published
Mean High Water Springs (MHWS)	4.12	4.20	3.94	3.96
Mean High Water Neaps (MHWN)	3.21	3.30	3.09	3.11
Mean Level (ML)	2.41	2.41	2.34	2.34
Mean Low Water Neaps (MLWN)	1.61	1.66	1.59	1.57
Mean Low Water Springs (MLWS)	0.70	0.76	0.74	0.72

The modelled velocities in the top half and bottom half of the water column are compared to bottom-mounted ADCP recordings in Figure 2-17 to Figure 2-22. The model was calibrated using the first six months of velocity recordings, and the model performance was validated using the last six months of recordings. The full set of figures covering the entire deployment period are provided in Appendix D. The agreement between the modelled and measured velocities is generally excellent at all six sites for both magnitude and direction. There are no significant stratification effects observed at any of the ADCP locations. There is a tendency for the model to underestimate the velocity magnitude for the bottom 50% of the water column at Site 3 and

overestimate the velocity magnitude for the top 50% of the water column at Site 4; this may be related to local bathymetric features or eddy structures which are not represented in the model, or due to significant local spatial variability in current magnitudes. Overall, the model is capable of accurately reproducing the measured water velocities.

Examples of the modelled and measured velocities across the ADCP transects (locations shown in Figure 2-7) are provided in Figure 2-23 to Figure 2-27 (the full set of figures are provided in Appendix E). The comparison shows that the model is able to accurately reproduce the measured velocity magnitude and direction. Some discrepancies are apparent particularly around the change of the tide, and are most likely due to slight phase variations as a result of using hindcast global model boundary conditions. Model resolution close to shore also limits direct comparison in some areas.

The modelled wave conditions during the calibration period are compared to wave data collected at the ADCP locations in Figure 2-28 to Figure 2-30 and at the Gladstone Waverider Buoy in Figure 2-31. The wave parameters are accurately reproduced by the model. There are occasional discrepancies between the modelled and recorded peak period and direction at ADCP 1, perhaps due to limitations in the accuracy of the NCEP CFSR wind field or bimodal spectra. There is significant scatter in the recorded wave direction at location ADCP 3, perhaps due to local sea breeze effects not captured in the NCEP CFSR model. This is not likely to cause any inaccuracy in the model outputs, in terms of project impact assessments, due to the relatively low wave heights at that location.

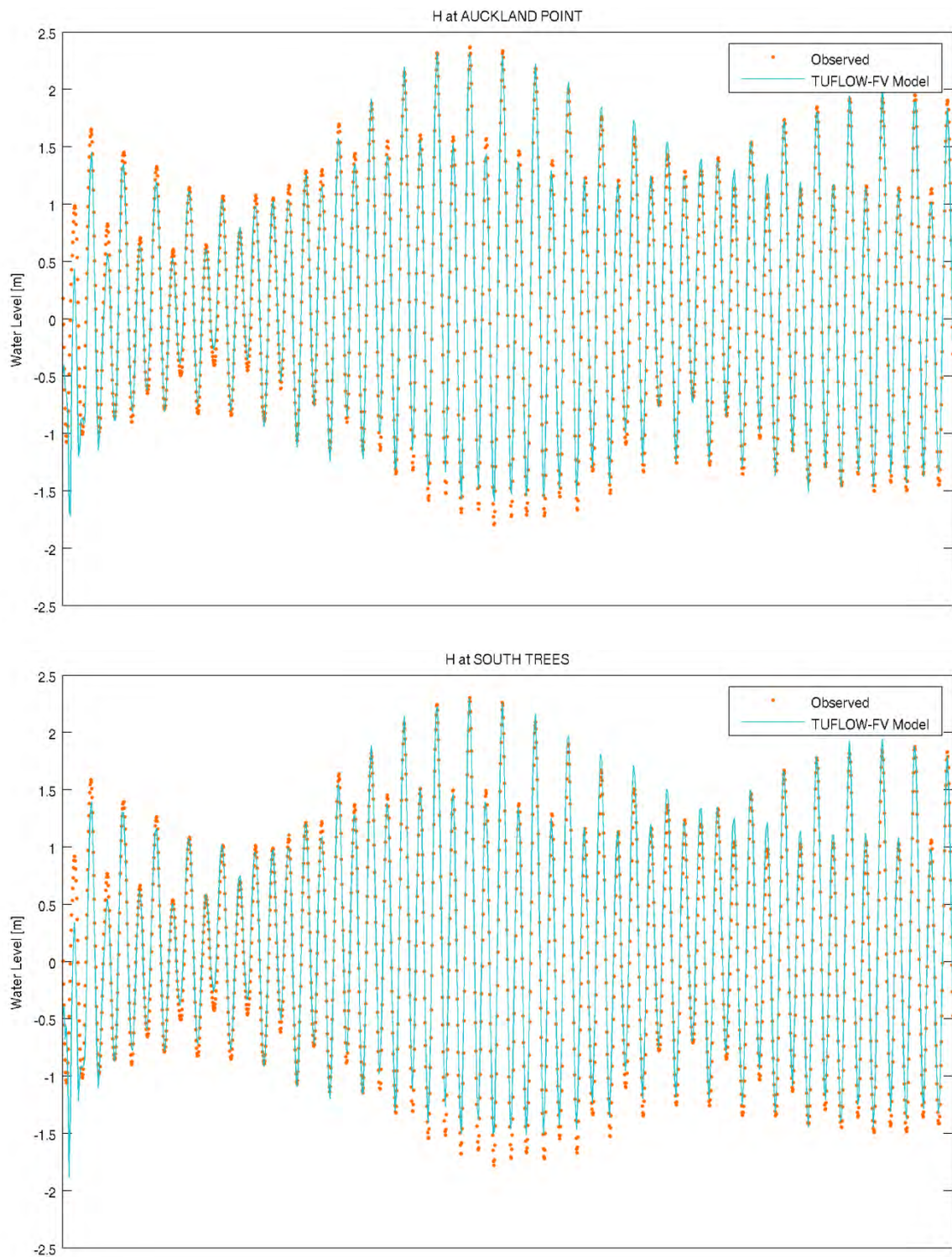


Figure 2-10 Water Level Calibration Plot at Tide Gauges
Auckland Point (MSQ) – Top Panel – MSE 0.022
South Trees (DES) – Bottom Panel – MSE 0.018

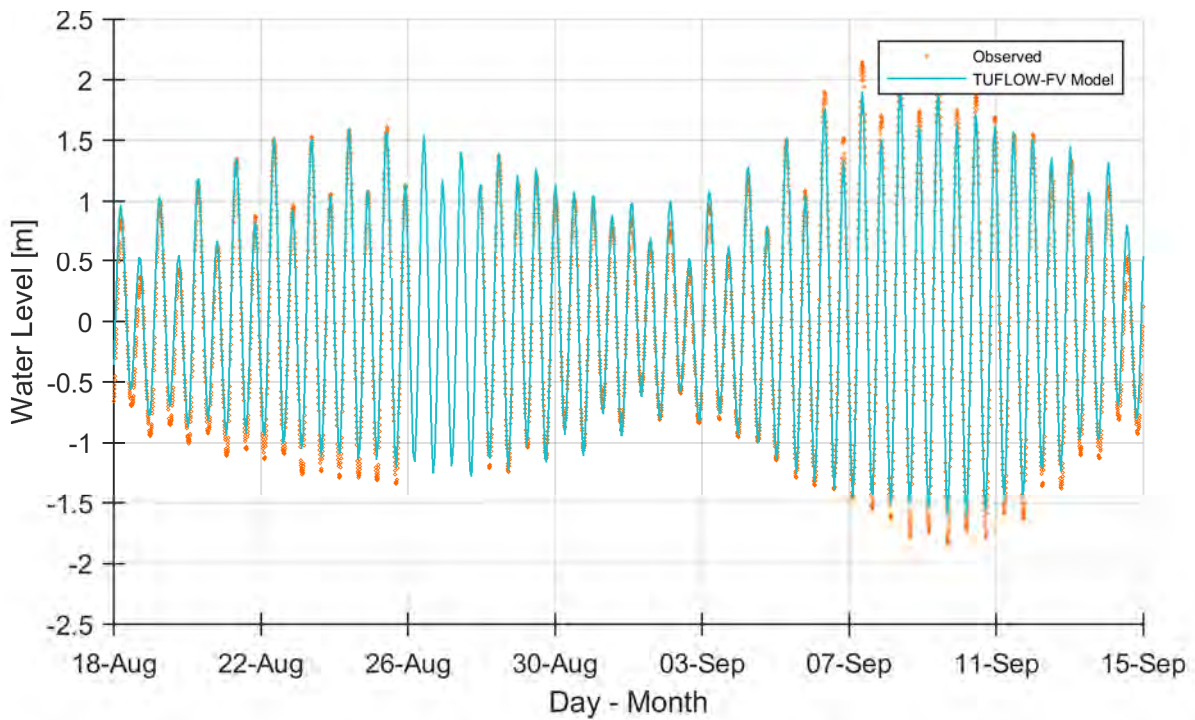


Figure 2-11 Water Level Calibration Plot at ADCP1 – MSE 0.0239

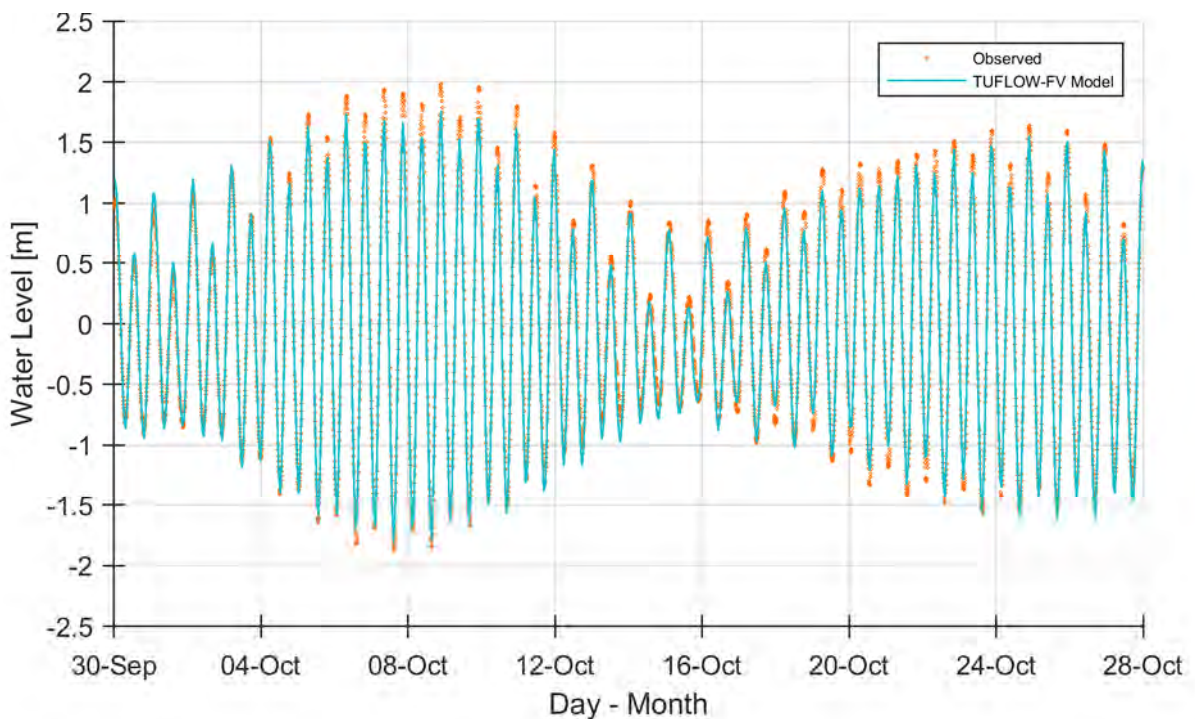


Figure 2-12 Water Level Calibration Plot at ADCP2 – MSE 0.0326

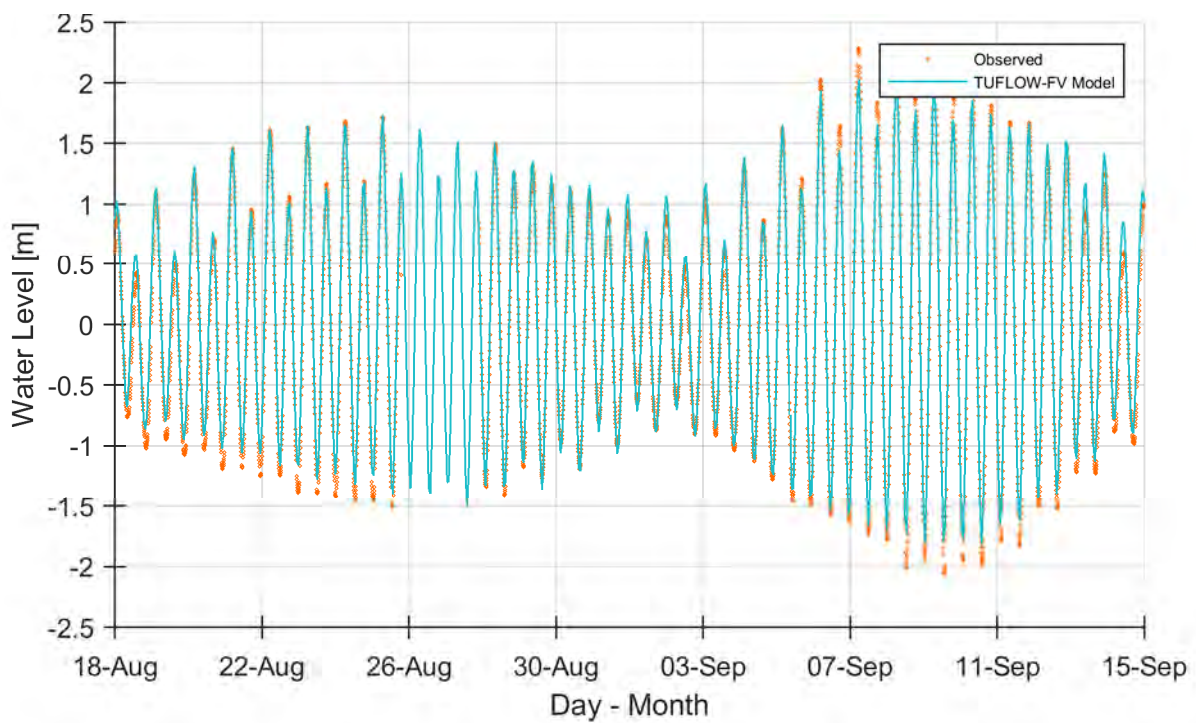


Figure 2-13 Water Level Calibration Plot at ADCP3 – MSE 0.0267

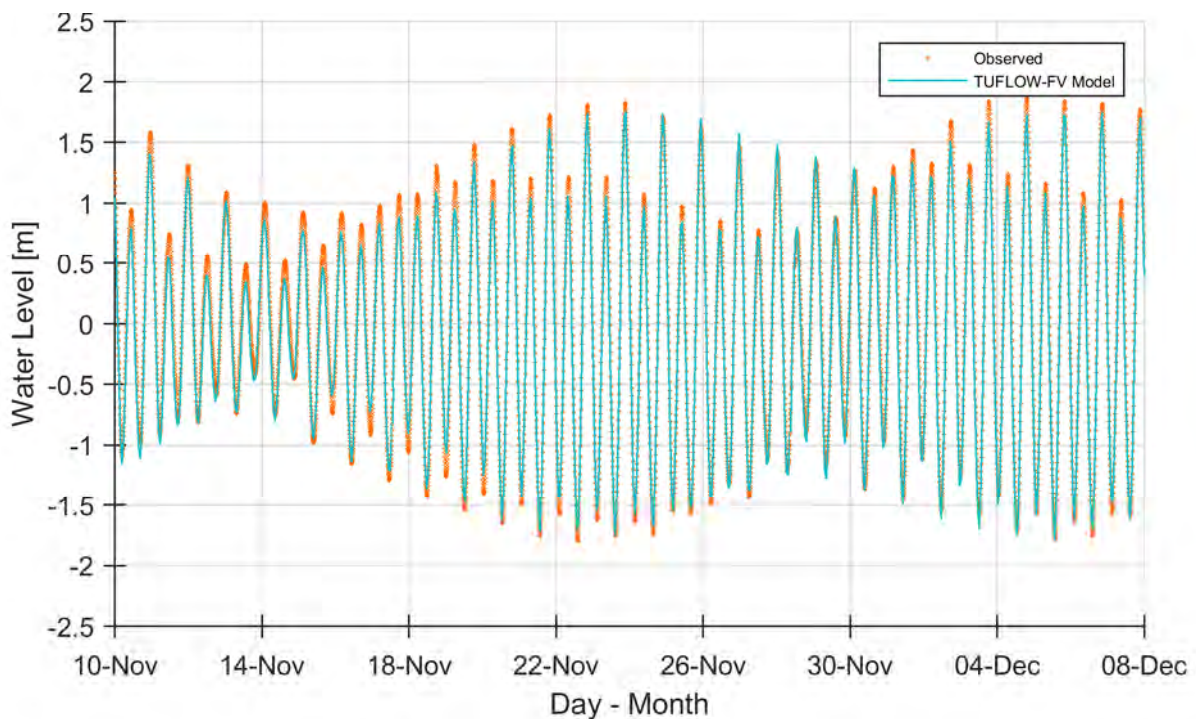


Figure 2-14 Water Level Calibration Plot at ADCP4 – MSE 0.0277

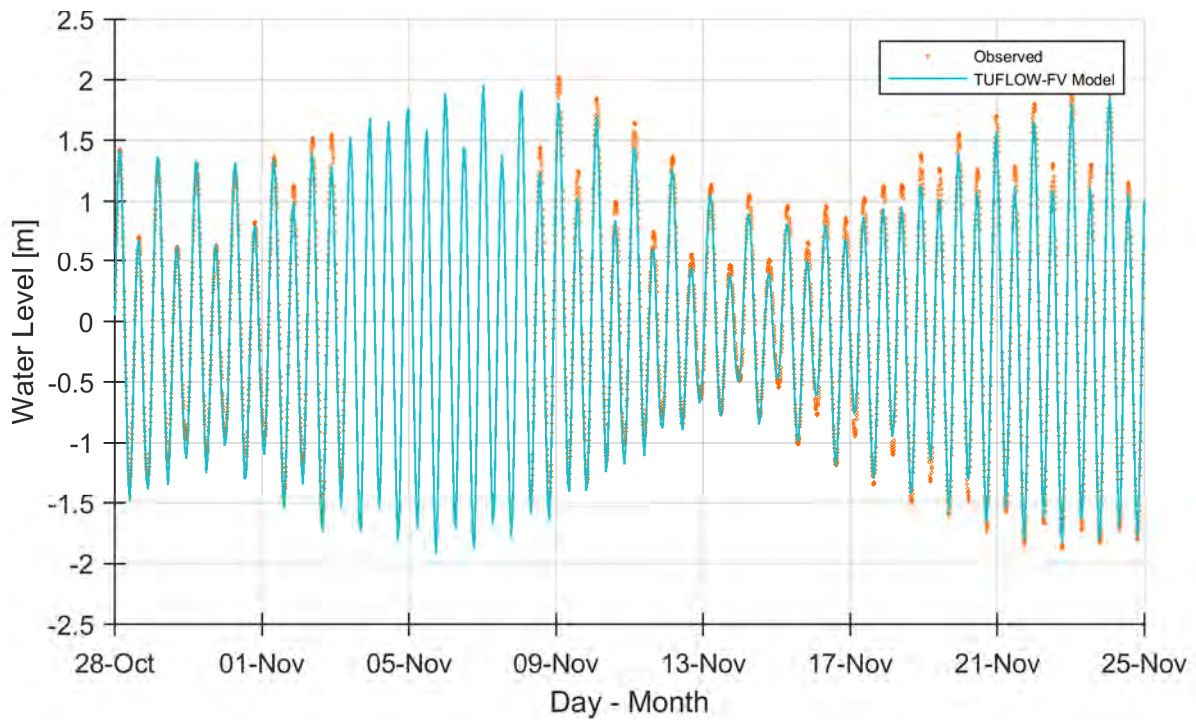


Figure 2-15 Water Level Calibration Plot at ADCP5 – MSE 0.0208

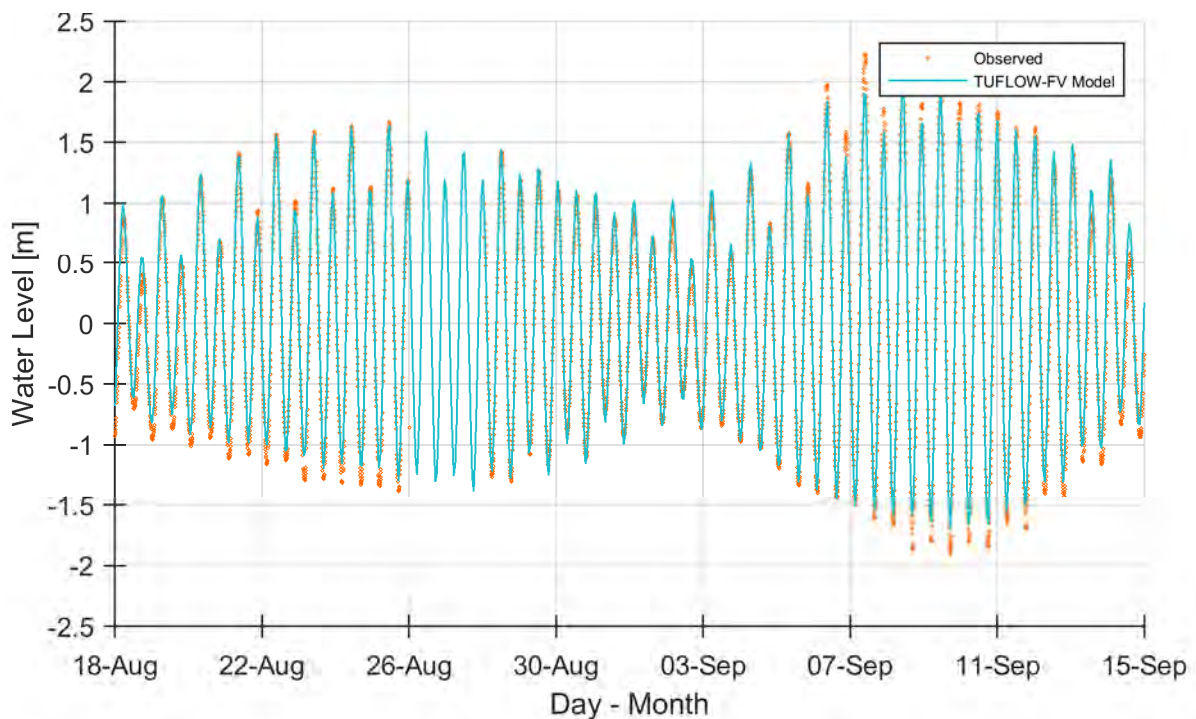


Figure 2-16 Water Level Calibration Plot at ADCP6 – MSE 0.0234

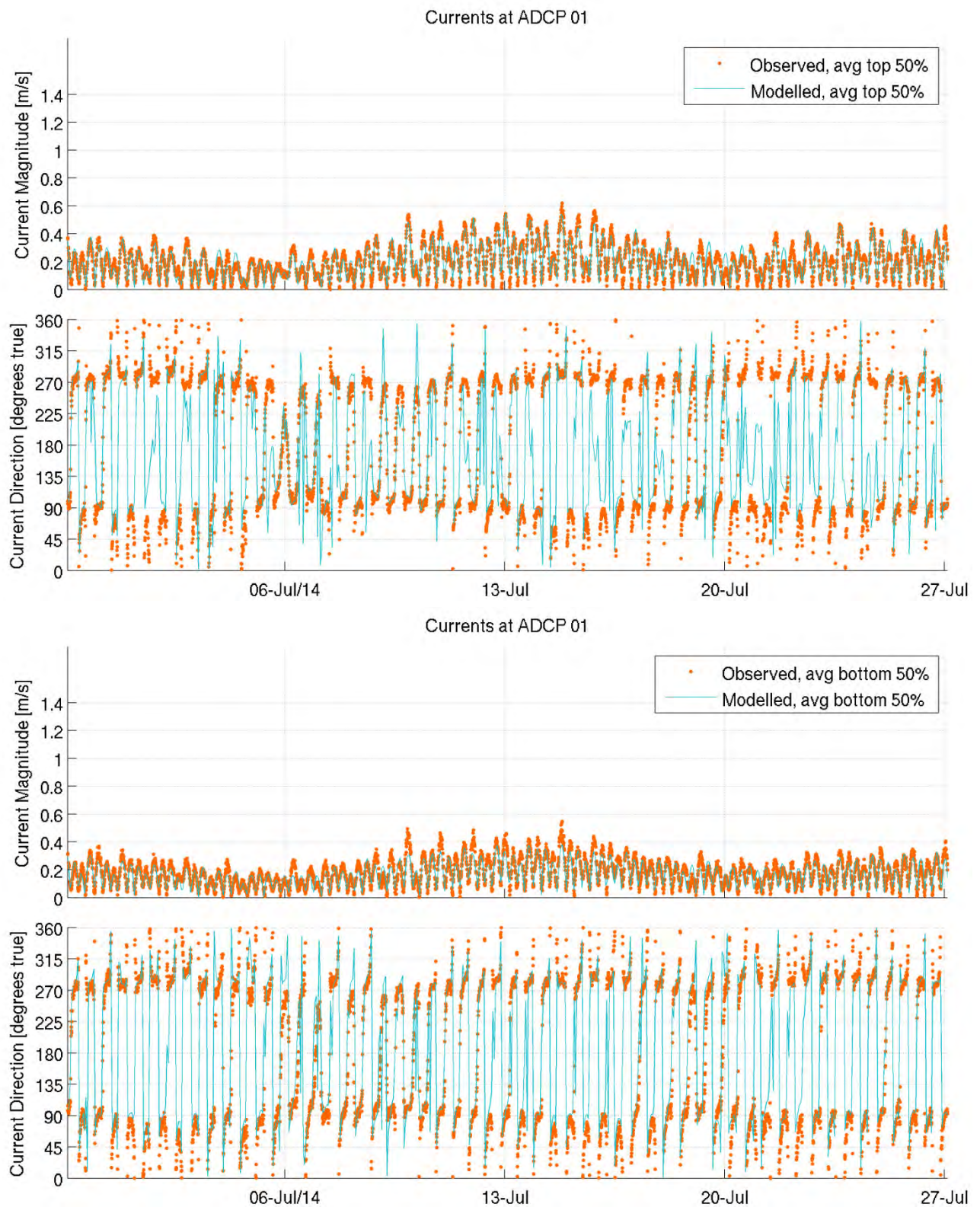
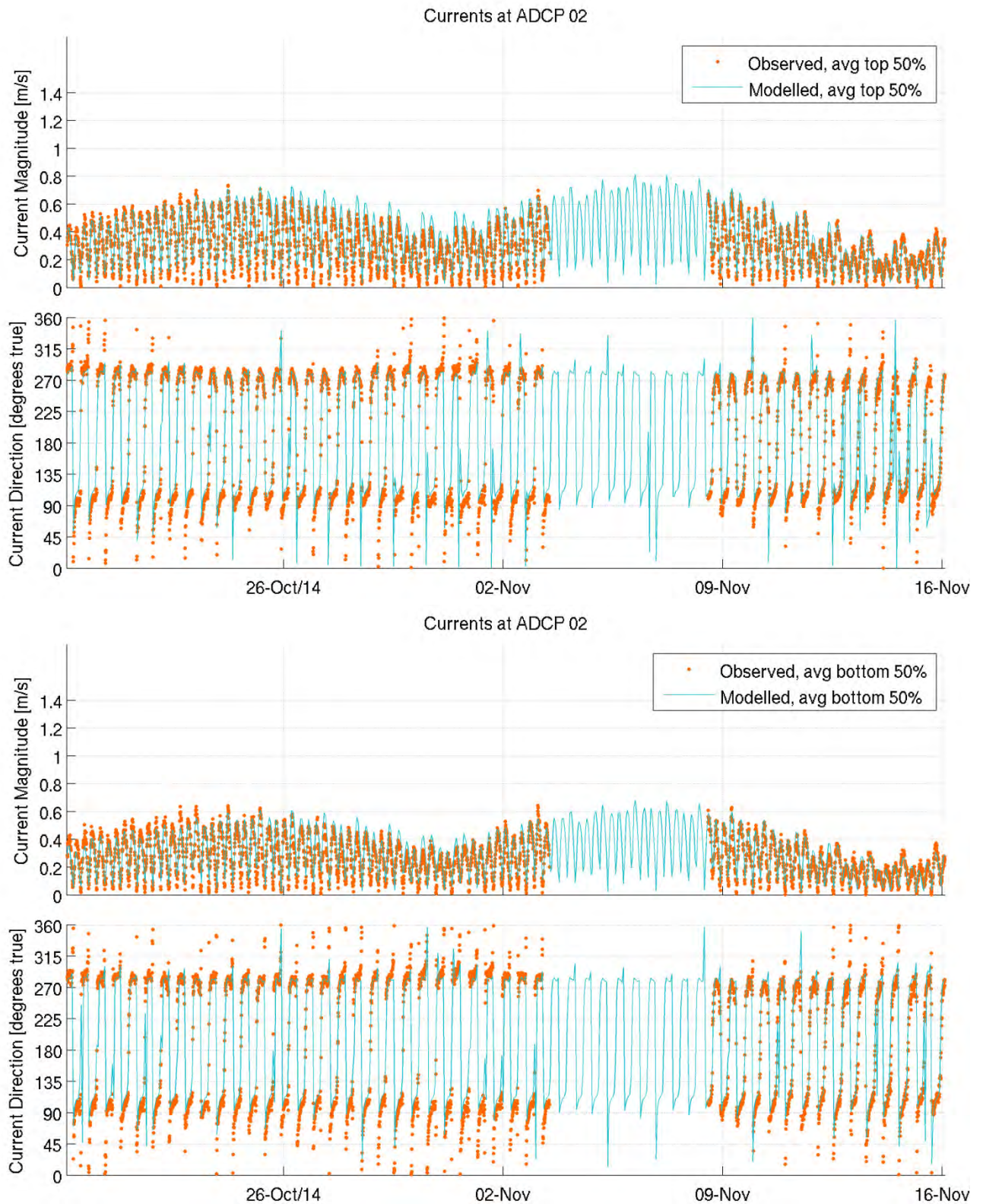


Figure 2-17 Velocity Calibration Plots at Location ADCP1
Top 50% of Water Column (Top) – MSE 0.0033
Bottom 50% of Water Column (Bottom) – MSE 0.0021



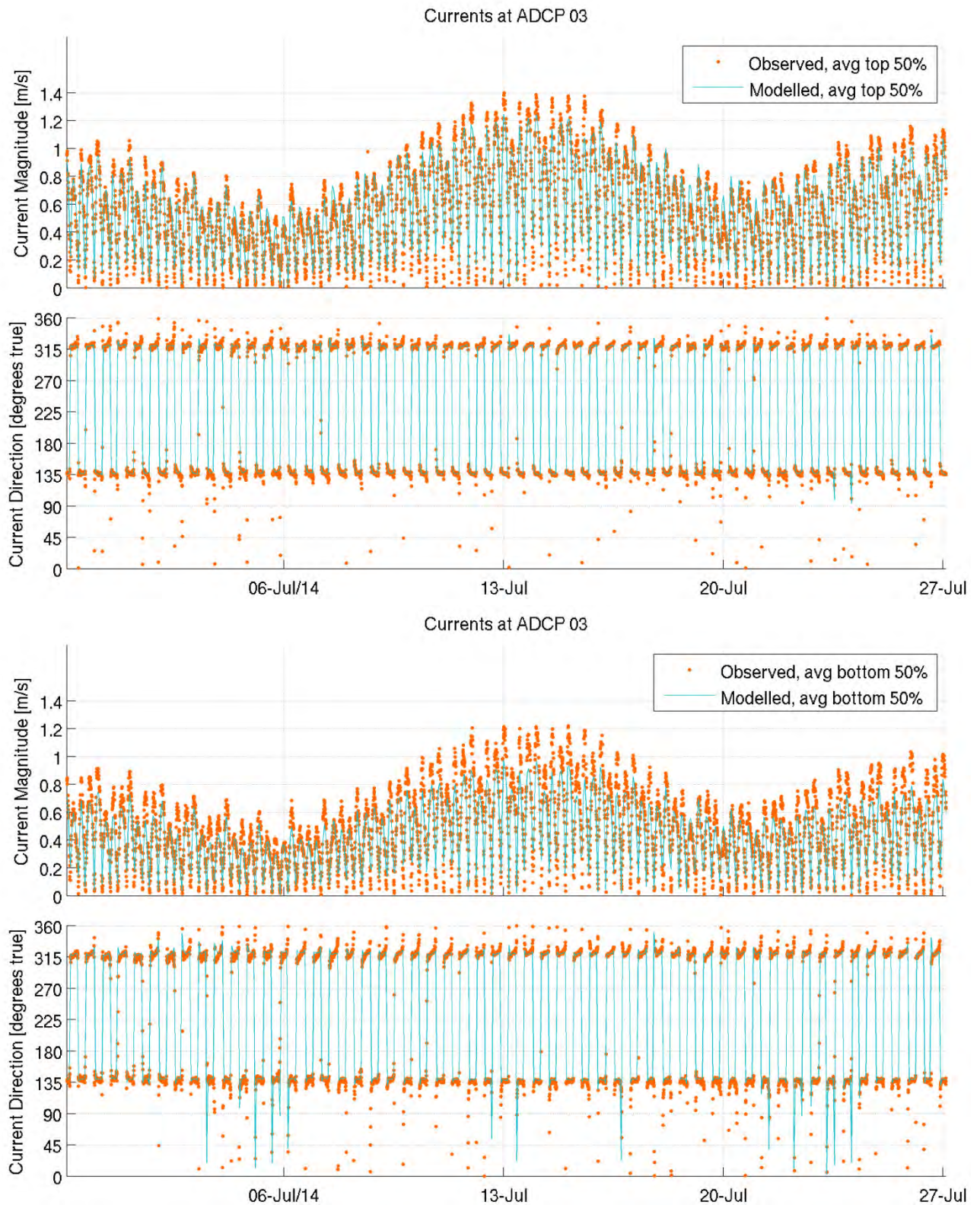
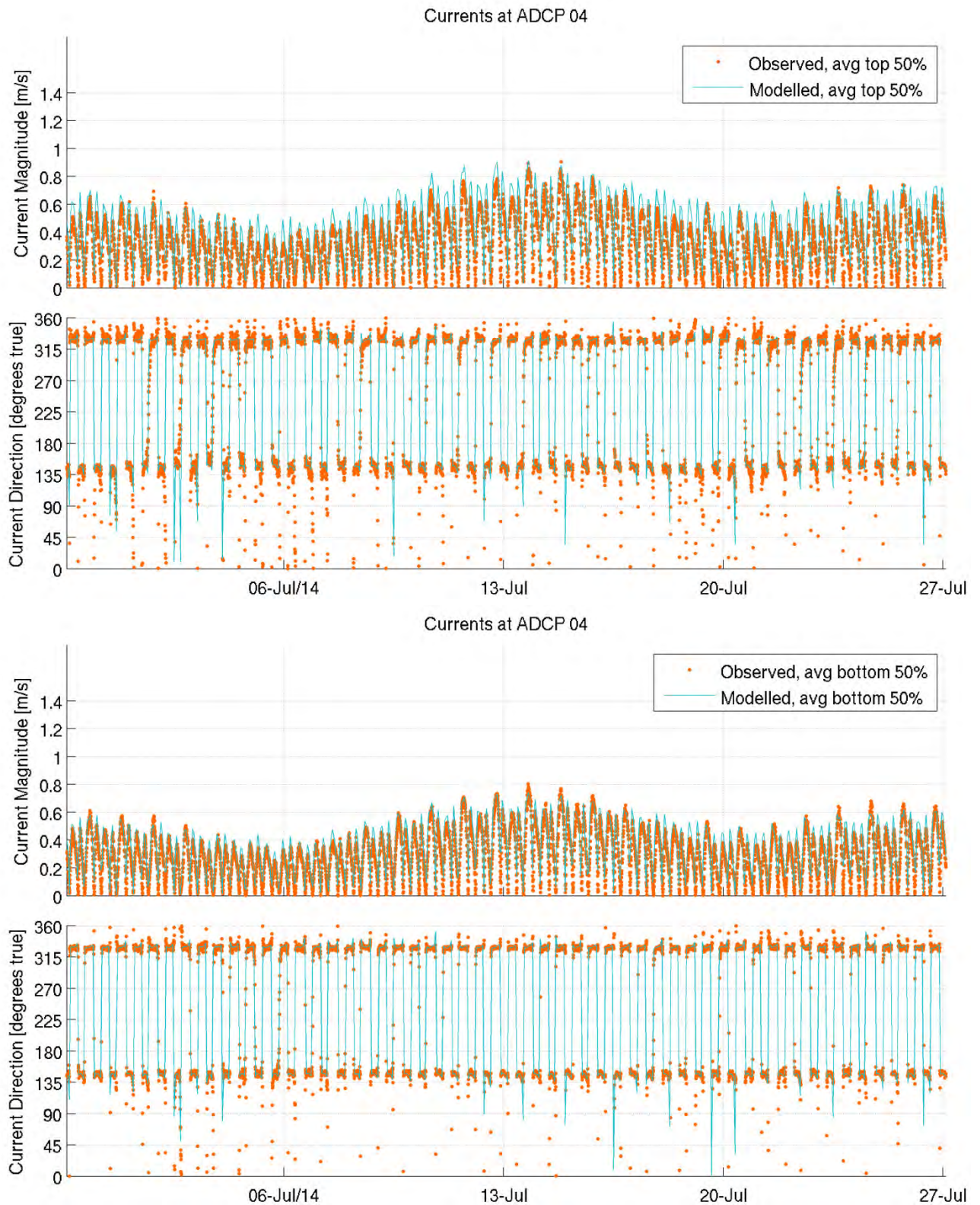


Figure 2-19 Velocity Calibration Plots at Location ADCP3
Top 50% of Water Column (Top) – MSE 0.0137
Bottom 50% of Water Column (Bottom) – MSE 0.0066



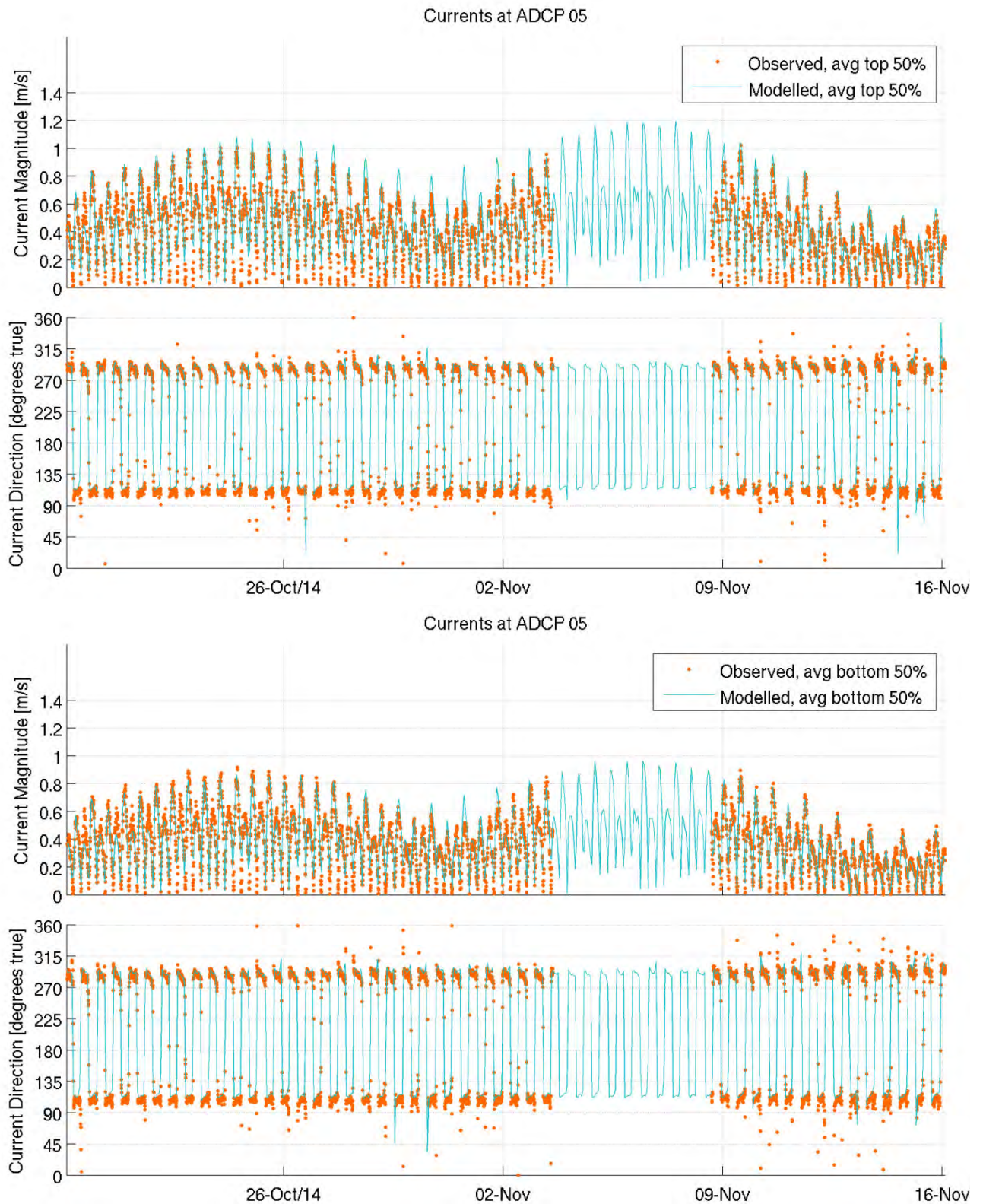
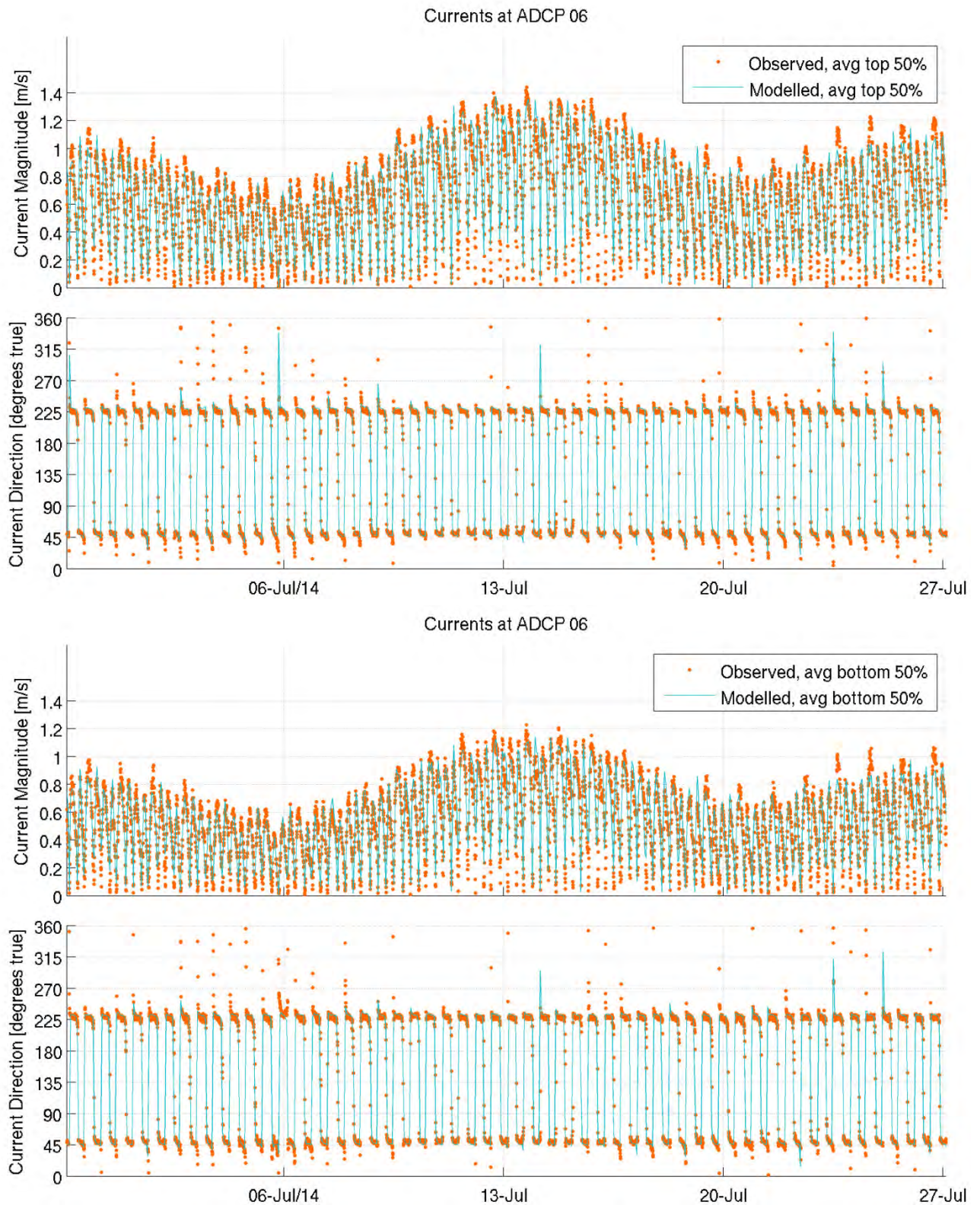


Figure 2-21 Velocity Calibration Plots at Location ADCP5
Top 50% of Water Column (Top) – MSE 0.0149
Bottom 50% of Water Column (Bottom) – MSE 0.0068



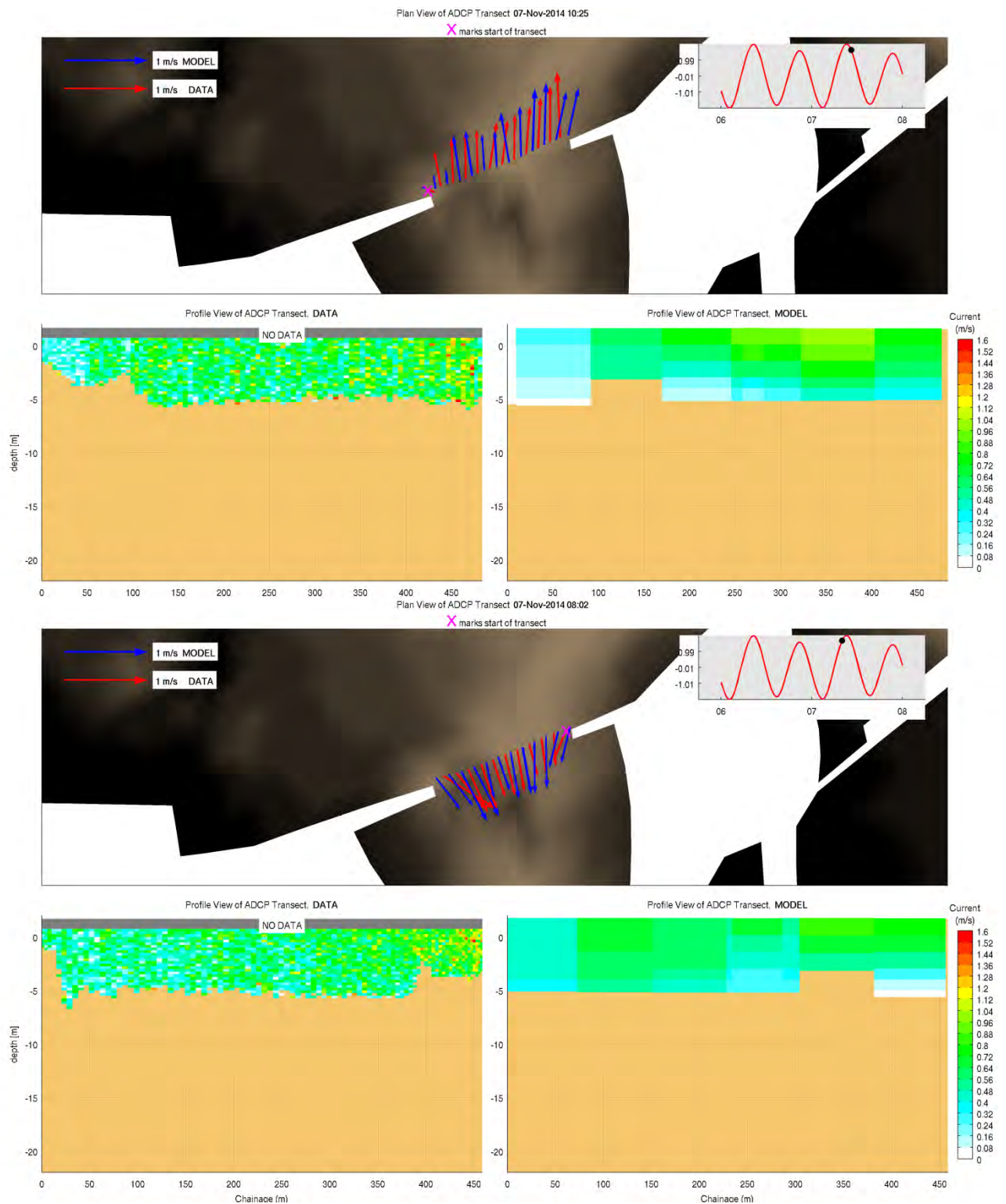


Figure 2-23 Transects at South Trees Inlet for Ebb-Tide (Top); and Flood-Tide (Bottom)

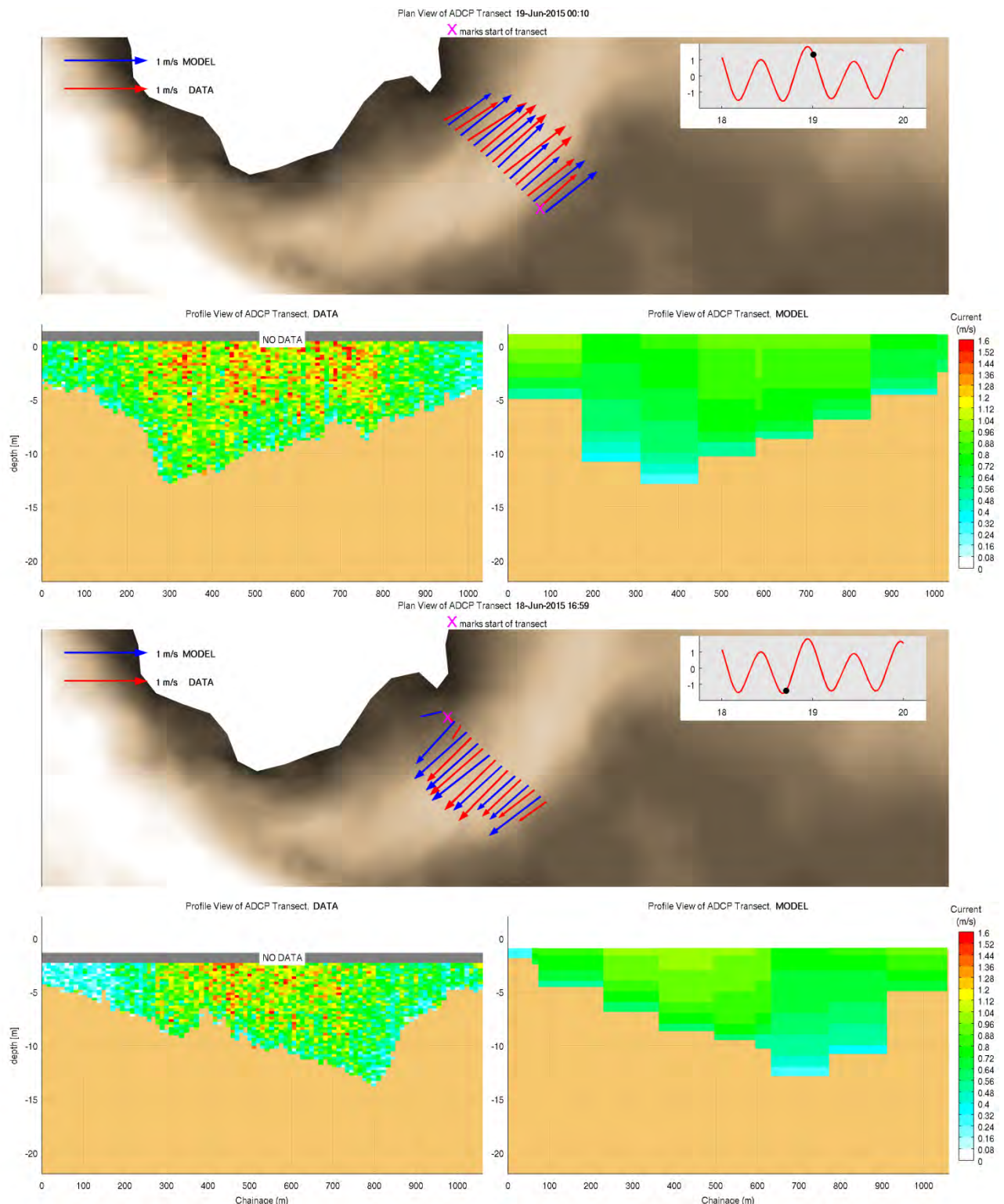


Figure 2-24 Transects South of Facing Island for Ebb-Tide (Top); and Flood-Tide (Bottom)

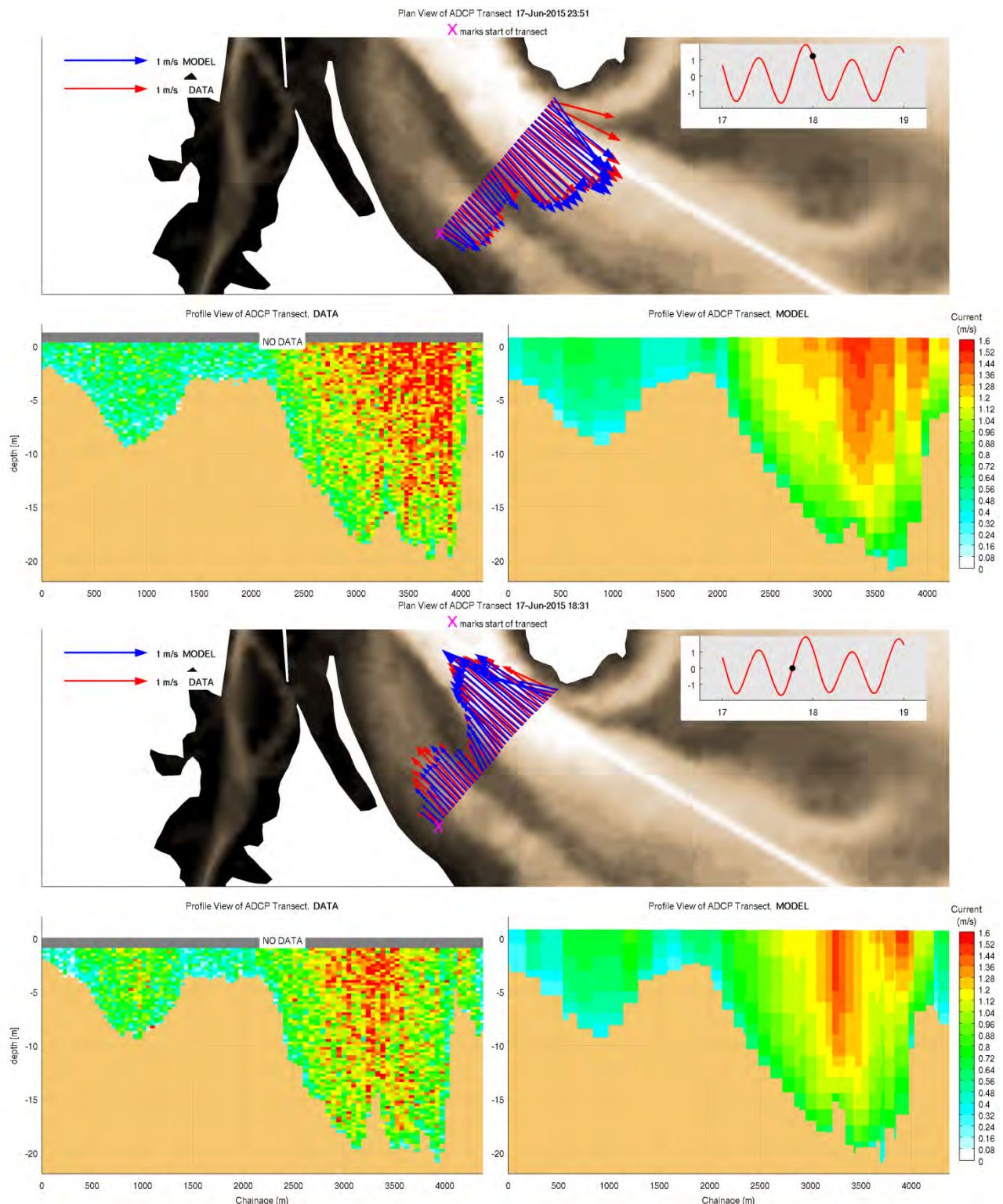


Figure 2-25 Channel Transects Near Facing Island Ebb-Tide (Top); and Flood-Tide (Bottom)

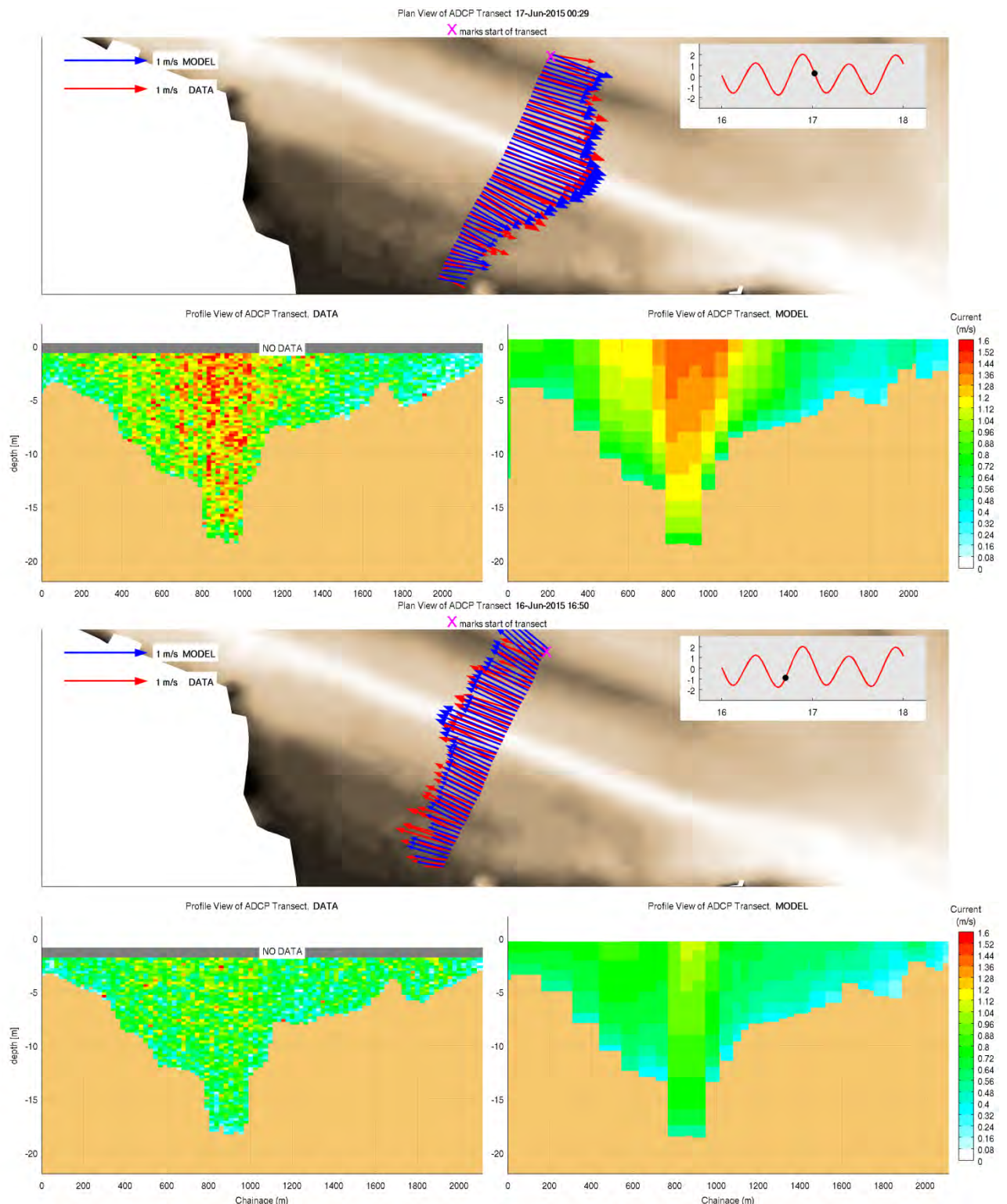


Figure 2-26 Port Central Transects for Ebb-Tide (Top); and Flood-Tide (Bottom)

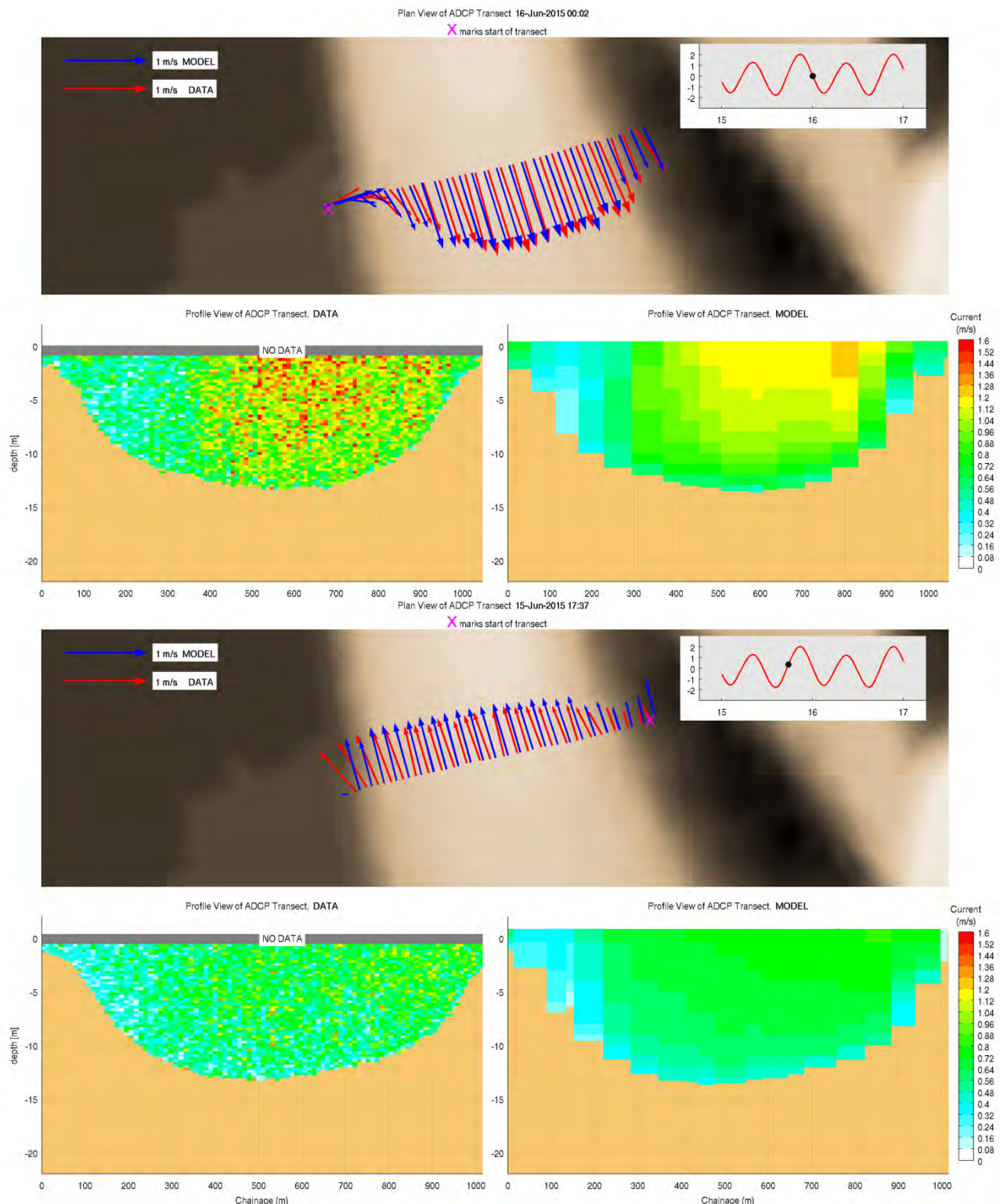
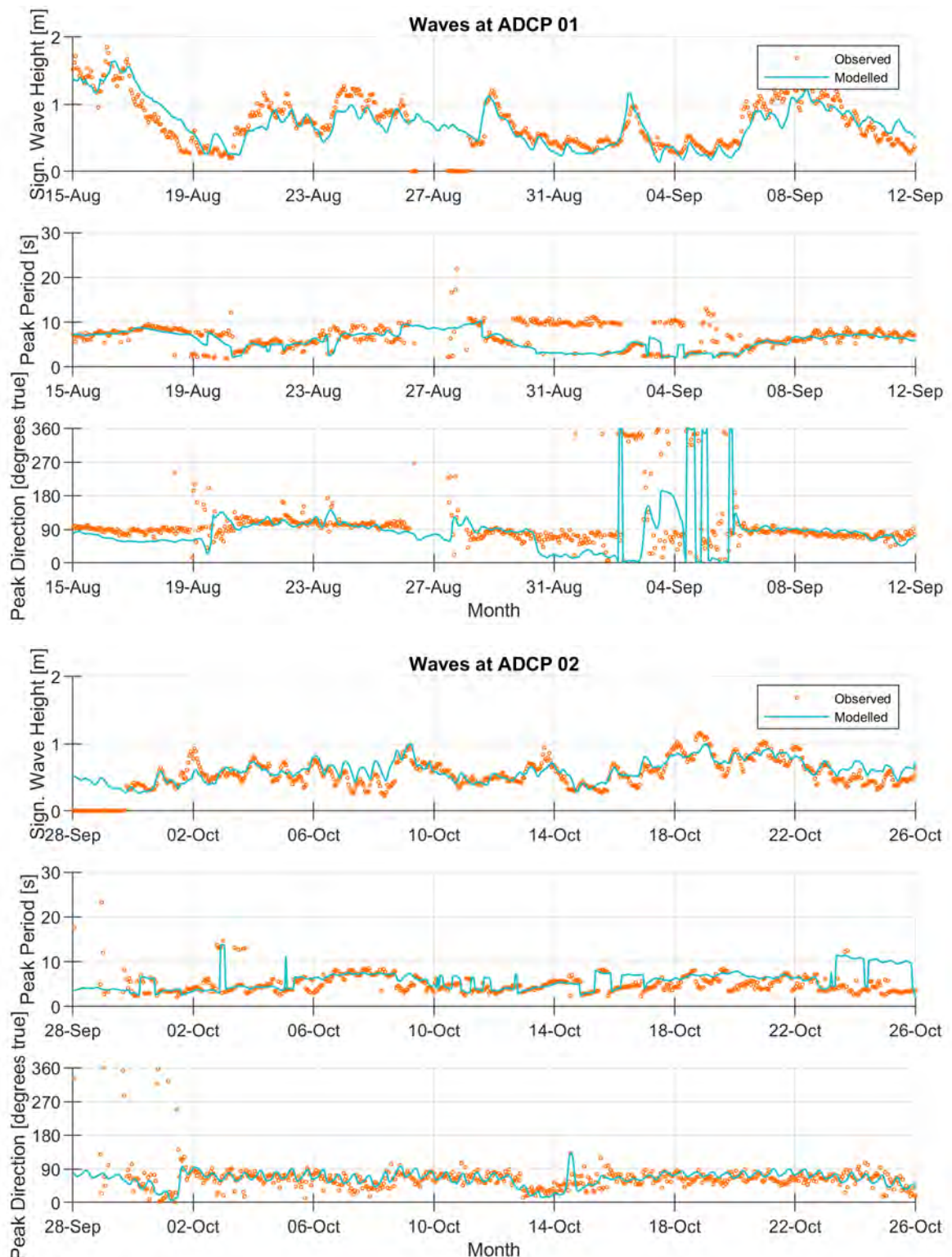
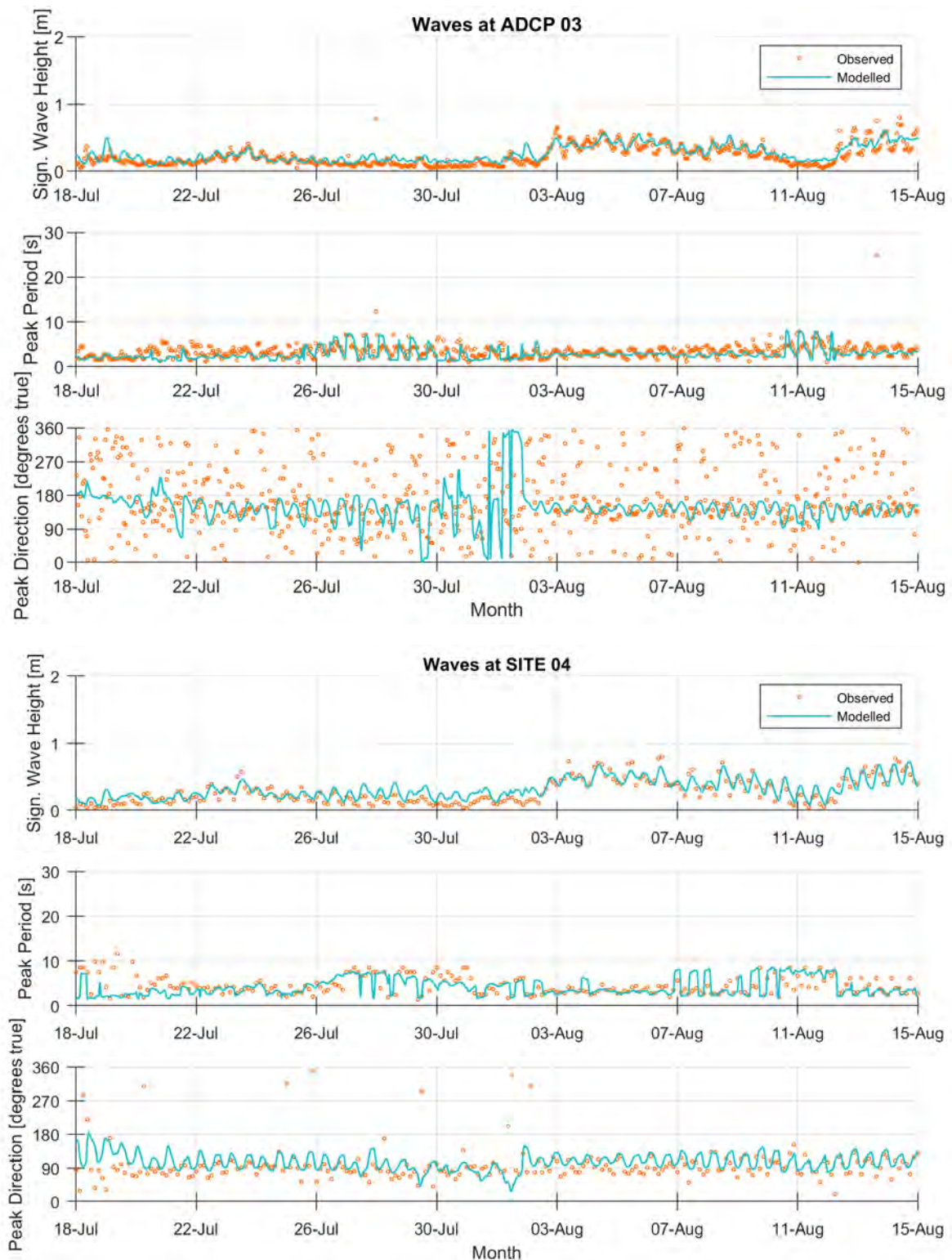


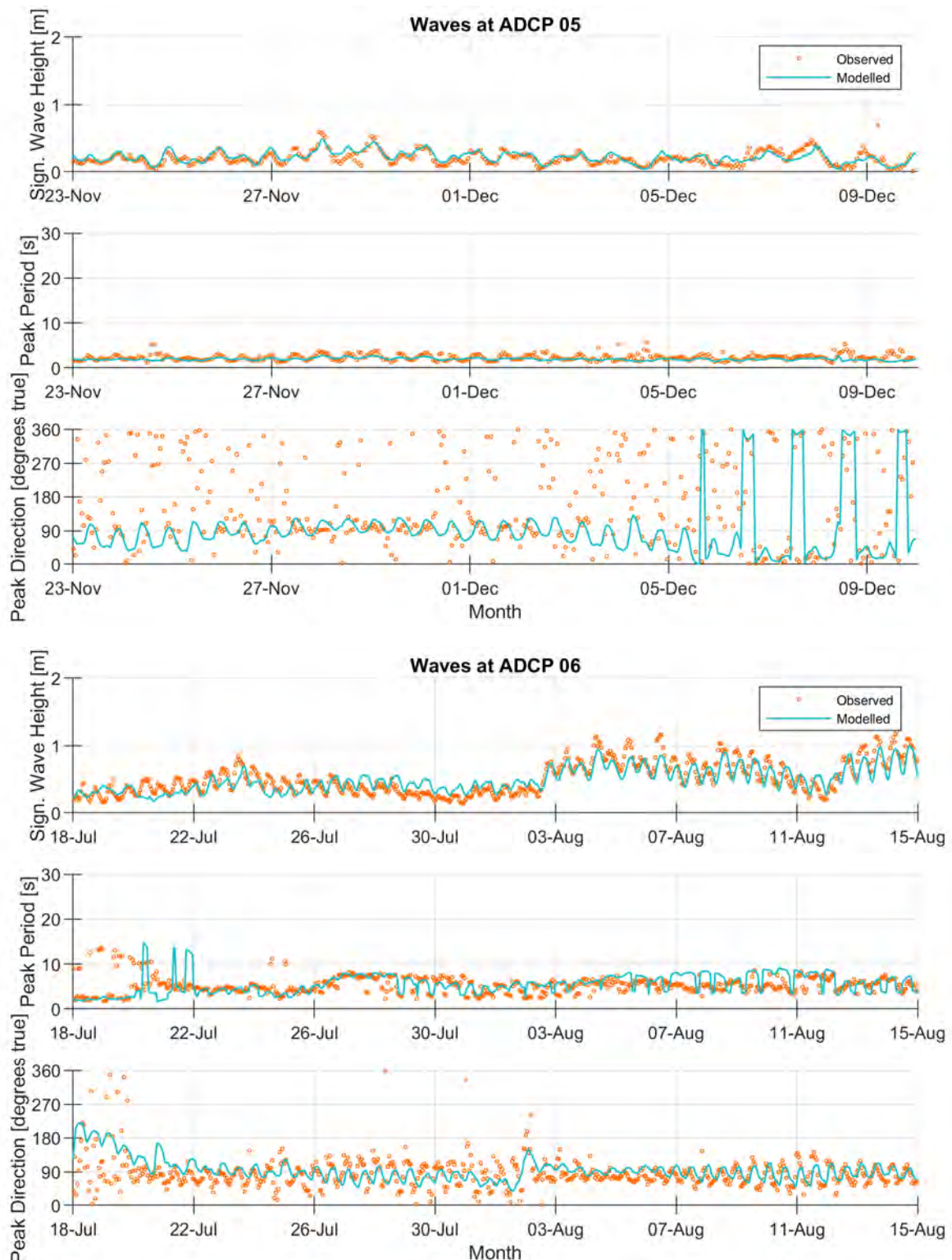
Figure 2-27 Transects Near Western Basin for Ebb-Tide (Top); and Flood-Tide (Bottom)



**Figure 2-28 SWAN Wave Model Calibration Plots
ADCP 1 (MSE for Hs 0.0655) and ADCP 2 (MSE for Hs 0.0326)**



**Figure 2-29 SWAN Wave Model Calibration Plots
ADCP 3 (MSE for H_s 0.0104) and ADCP 4 (MSE for H_s 0.0581)**



**Figure 2-30 SWAN Wave Model Calibration Plots
ADCP 5 (MSE for Hs 0.0094) and ADCP 6 (MSE for Hs 0.0293)**

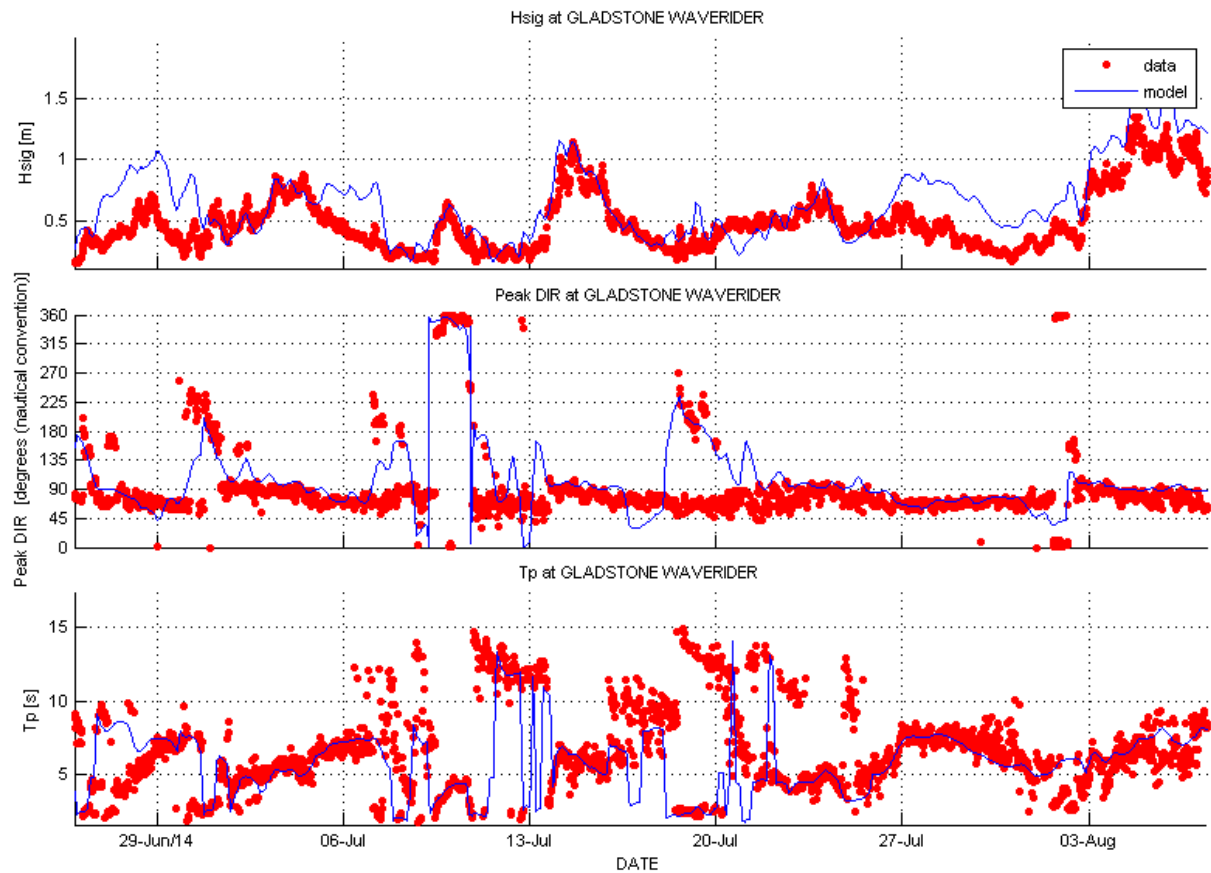


Figure 2-31 SWAN Wave Model Calibration Plot – Gladstone Waverider Buoy

2.5.2 Sediment Dynamics Calibration

In order to accurately assess the potential impacts of dredging-related suspended sediment plumes, it is important to include natural (ambient) sediments in the simulation. This allows for the mixing of dredged sediment and natural sediment within the model, and also allows an assessment of the relative significance of the dredging-related turbidity compared to the ambient turbidity.

The TUFLOW FV model was run for the period 25 June 2014 to 1 July 2015 in order to simulate the ambient sediment dynamics within Port Curtis. The wave rose at the Gladstone Waverider Buoy for this period is shown in Figure 2-8.

TUFLOW FV simulates the advection and dispersion of suspended sediment, as well as the exchange of sediments between the bed and the water column. The clear water sediment settling velocity, w_s , is directly specified and is assumed to have no dependence on suspended sediment concentration (e.g. flocculation or hindered settling), with these effects being treated implicitly in the calibration process. The modelled rate of sediment deposition is a function of the total suspended sediment concentration (TSS), the still-water fall velocity (w_s) and the combined wave-current bed shear stress (τ_b), according to the relationship:

$$Q_d = w_s \cdot TSS \cdot \max\left(0, 1 - \frac{\tau_b}{\tau_{cd}}\right) \quad [\text{g/s per m}^2]$$

where τ_{cd} is a model parameter defining the critical shear stress for deposition. As such, sediment settling is reduced below its still water value by the action of bed shear stress and associated vertical mixing in the water column. The rate of erosion is calculated according to:

$$Q_e = E \cdot \max\left(0, \frac{\tau_b}{\tau_{ce}} - 1\right) \quad [\text{g/s per m}^2]$$

where Q_e is the erosion rate, E is an erosion rate constant and τ_{ce} is the critical bed shear stress for erosion. Three sediment types were modelled, with settling velocities shown in Table 2-4. Note that the adopted settling velocity for each type are essentially calibration parameters in this case, only roughly corresponding to the broad sediment classes of 'fine sand', 'silt' and 'clay', in order to implicitly account for fine-scale processes (e.g. flocculation and hindered settling).

Table 2-4 Settling Velocities for Each Sediment Type

Sediment Type	Settling Velocity (m/s)
Fine Sand	1×10^{-2}
Silt	1×10^{-3}
Clay	1×10^{-4}

Since the available data on the seabed sediment composition is very limited, the existing seabed distribution of fine sediment within Port Curtis was approximated in the model by running a 'warmup' simulation. This simulation was run with an initial condition of a uniform thickness of 100mm of sediment throughout the model (30% non-erodible sediments, 40% fine sand, 20% silt and 10% clay), allowing redistribution of the sediment to occur such that energetic parts of the model (e.g. the main channels) had sediment removed from the bed while sediment accumulated in other parts of the model (e.g. mud flats). Use of a model that was not 'warmed up' would result

in re-suspension predictions that are incorrectly dominated by erosion from zones that are unlikely to harbour mobile fine sediments. Bed morphology changes were not included in the 'warmup' simulations (i.e. bed levels remained fixed in the model).

Comparison of the measured and modelled turbidity from a series of calibration runs (varying the erosion rate and the critical shear stress thresholds) led to the choice of the following parameters:

$$\tau_{ce} = 0.2 \text{ N/m}^2 \quad \tau_{cd} = 0.1 \text{ N/m}^2 \quad E = 0.05 \text{ g/m}^2/\text{s}$$

The adopted parameter sets are well within the accepted literature ranges. A turbidity to TSS relationship of $\text{TSS} = 1.6 \times [\text{measurement in Nephelometric Turbidity Units (NTU)}]$ has been used based on analysis of data collected during the Western Basin Dredging and Disposal Project (refer Figure 2-32). Turbidity and TSS data were also collected for this Project, however due to the low magnitude of TSS in the samples (refer Figure 2-33), these recordings were not used in the derivation of the relationship (but the relationship adopted is also a good fit to this data).

A comparison of the measured and modelled turbidity (in NTU) at instrument locations is shown in Figure 2-34 to Figure 2-41. The benthic turbidity sensors were located approximately 1.5 m above the seabed, so the recorded data was compared to the model results from the bottom 3 m of the water column, while the data from the surface sensors was compared to the model results from the top 3 m of the water column. The results indicate that the model generally reproduces the broad range of suspended sediment dynamics for natural conditions. The variation of turbidity levels between spring and neap periods is captured, as is the semi-diurnal variation in turbidity levels during a single tide cycle. The modelled turbidity level is sometimes lower than the recorded level and sometimes higher, and the semi-diurnal range is underestimated in some cases. This is likely partly due to limitations in the accuracy of the seabed 'warmup' process, and may also be affected by high spatial gradients in turbidity and overall limitations in model accuracy such as the assumed vertical mixing model and horizontal and vertical resolution. The ambient sediment dynamics are extremely complex, and the model performance is considered to be very good considering the difficulty of the modelling task. Note that the assessment of the turbidity and sedimentation impacts associated with dredging are not very sensitive to the accuracy level of the ambient sediment dynamics modelling, since the ambient dynamics are included only to provide context and to allow more realistic modelling of resuspension processes.

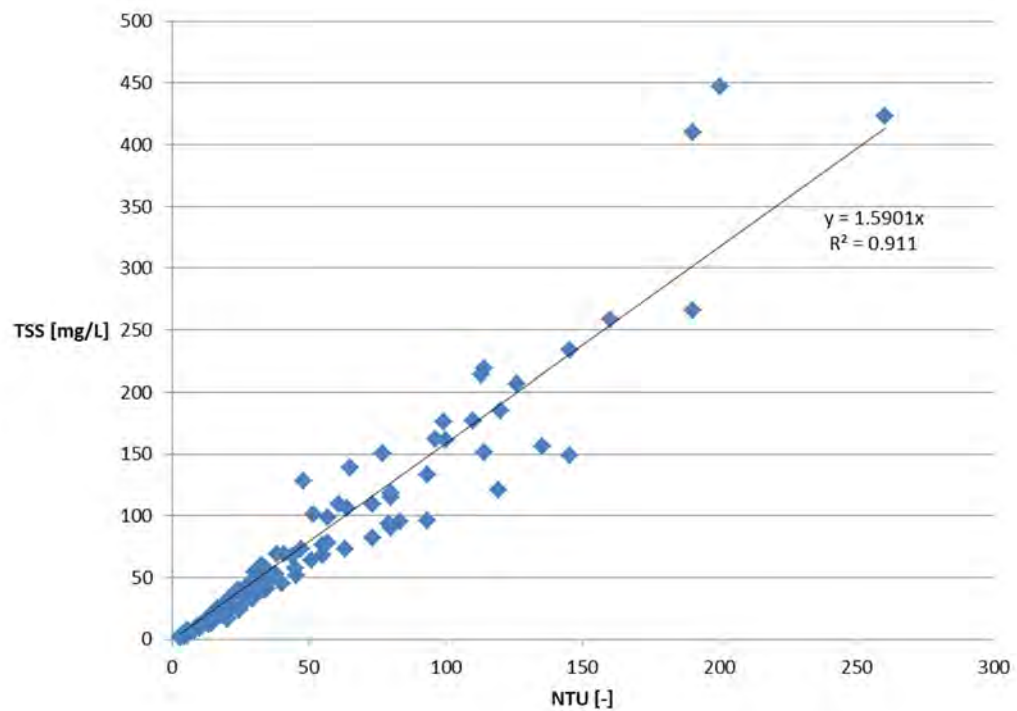


Figure 2-32 TSS–NTU Relationship During Western Basin Dredging and Disposal Project
Samples n = 139

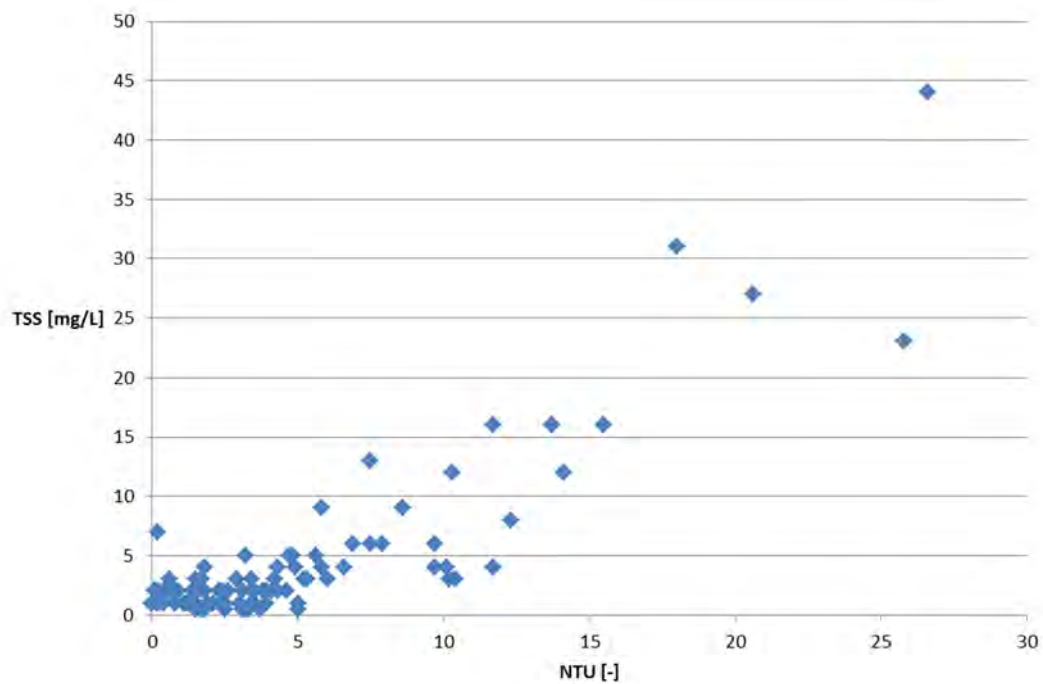


Figure 2-33 TSS–NTU Data Collected June 2014 to June 2015
Samples n = 105

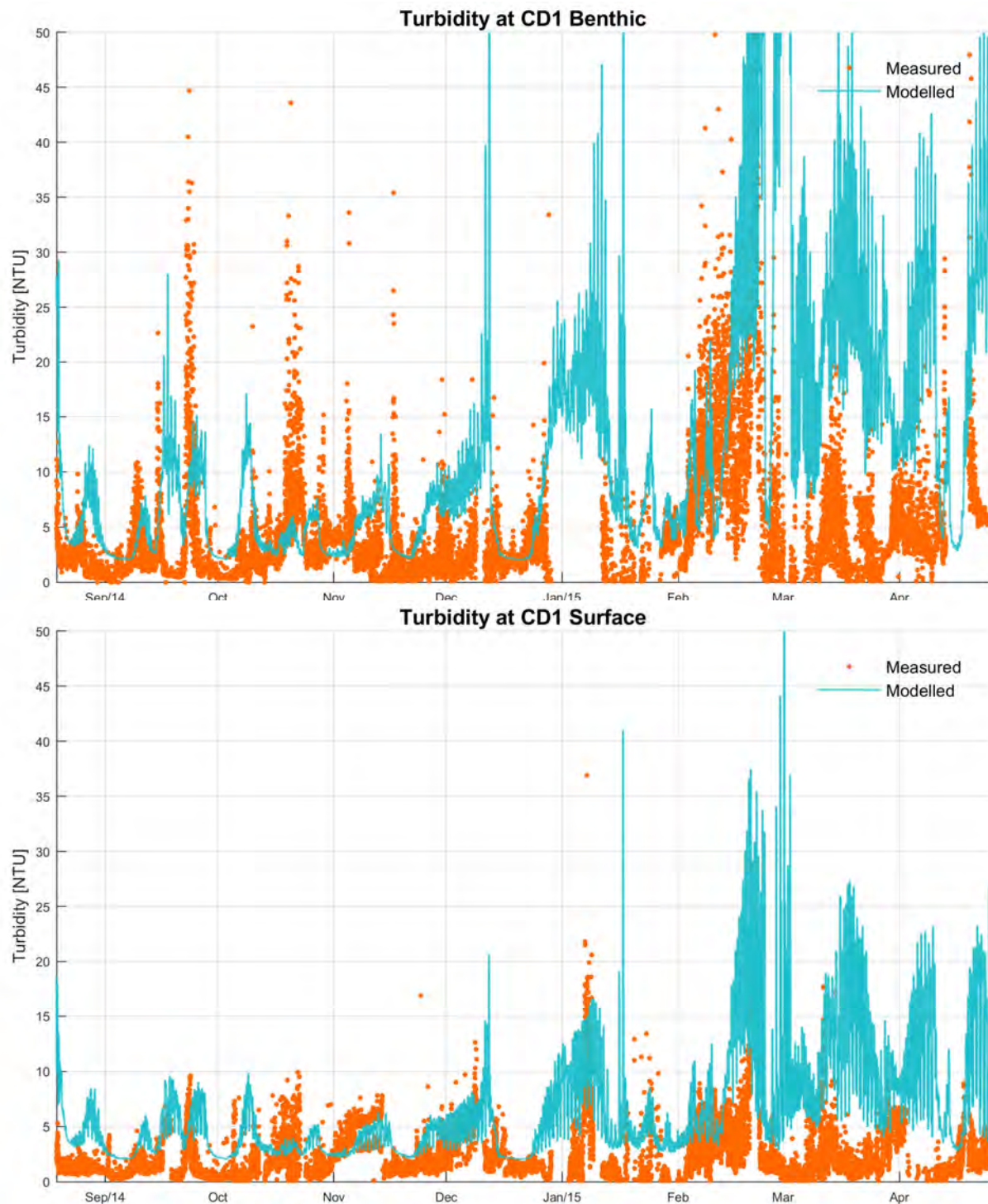


Figure 2-34 Ambient Turbidity Calibration Plots – Site CD1

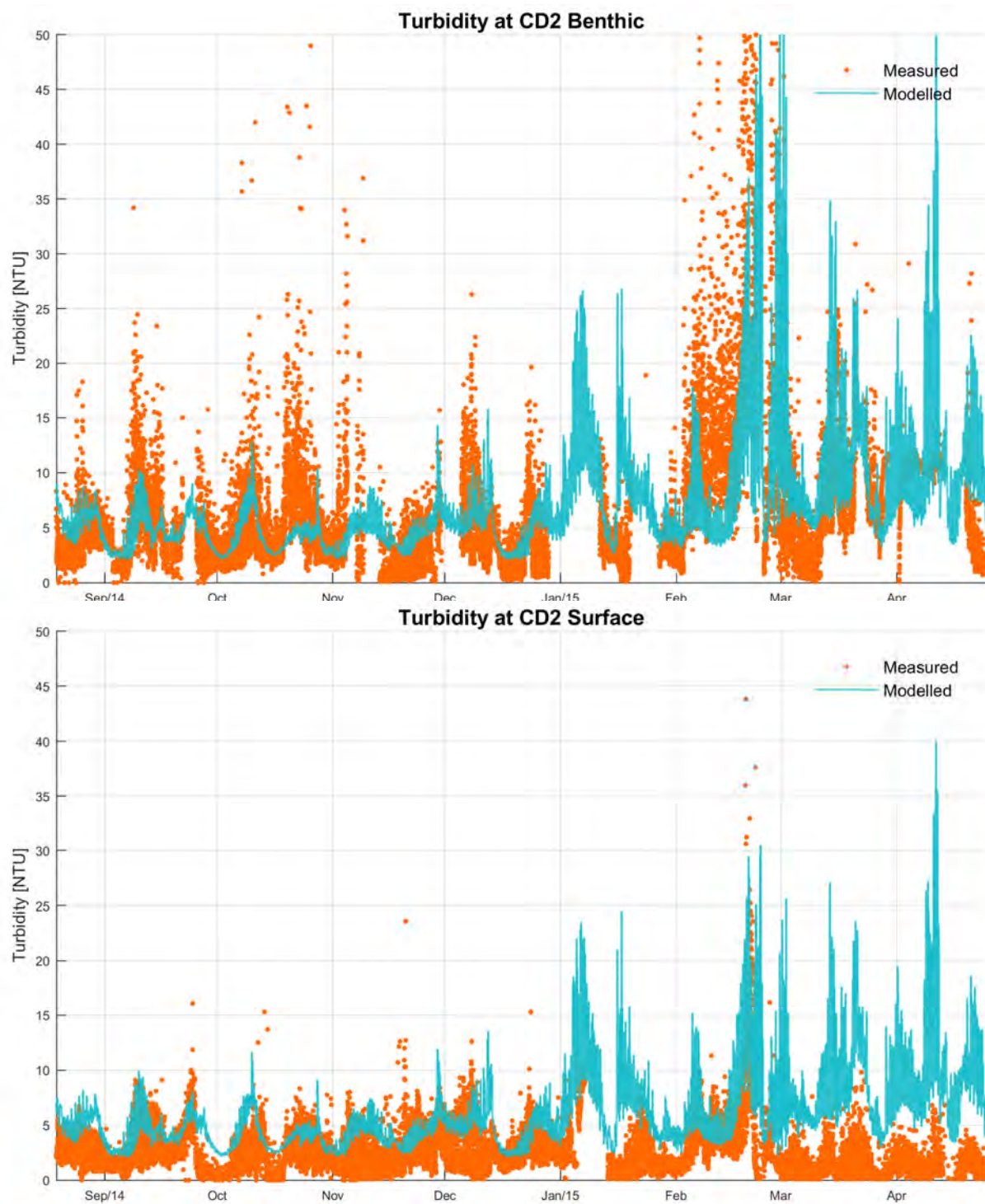


Figure 2-35 Ambient Turbidity Calibration Plots – Site CD2

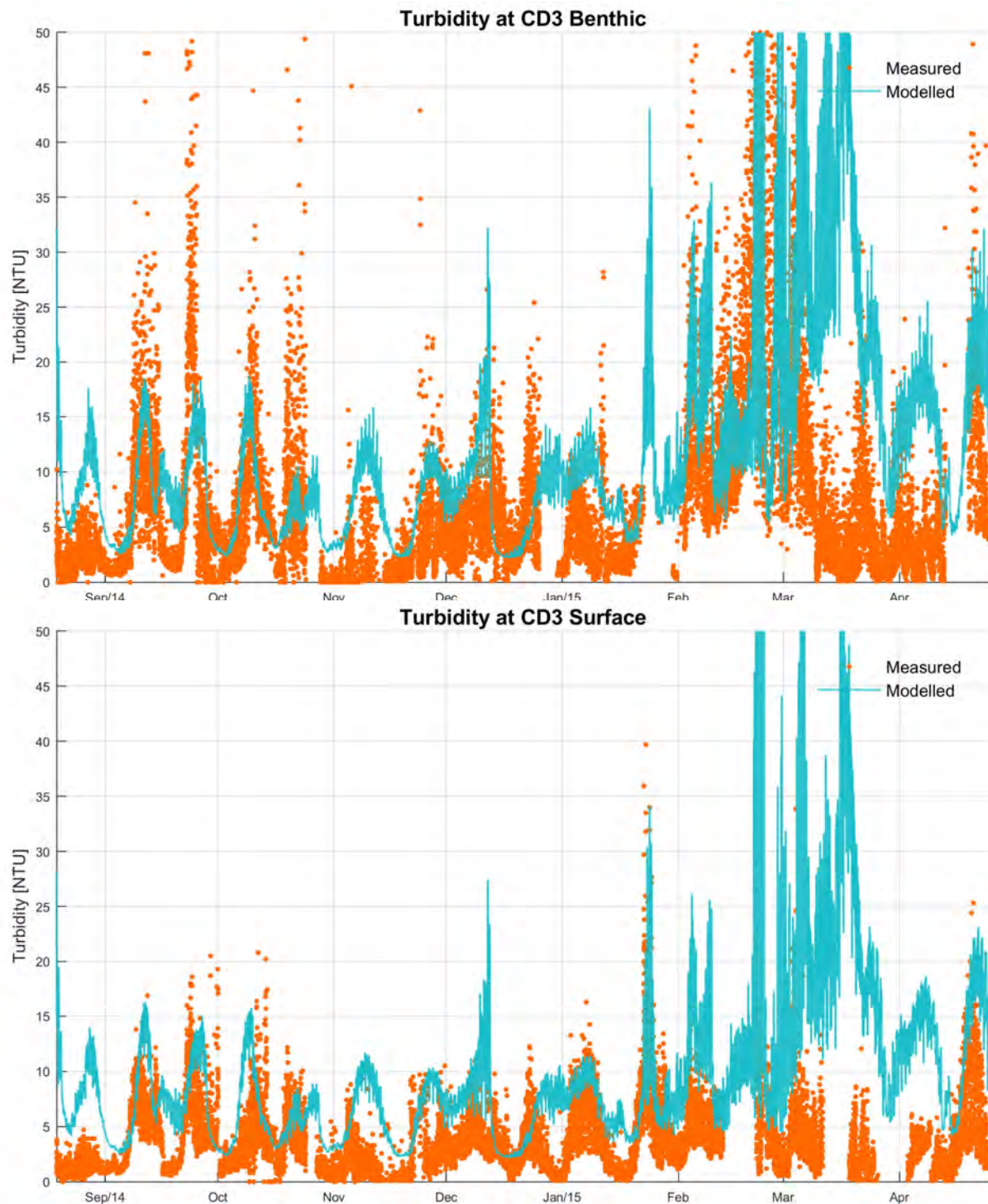


Figure 2-36 Ambient Turbidity Calibration Plots – Site CD3



Figure 2-37 Ambient Turbidity Calibration Plots – Site CD4

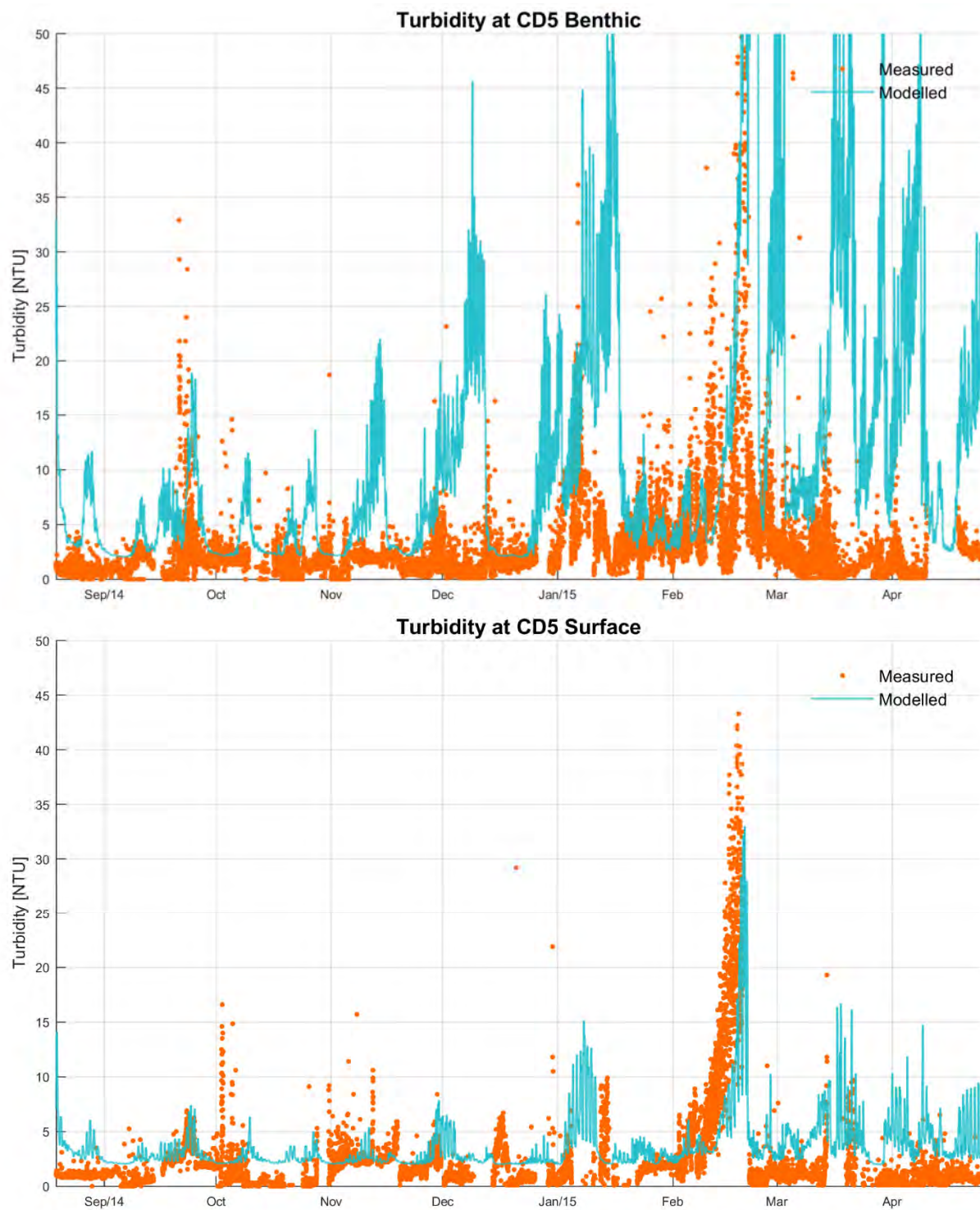


Figure 2-38 Ambient Turbidity Calibration Plots – Site CD5

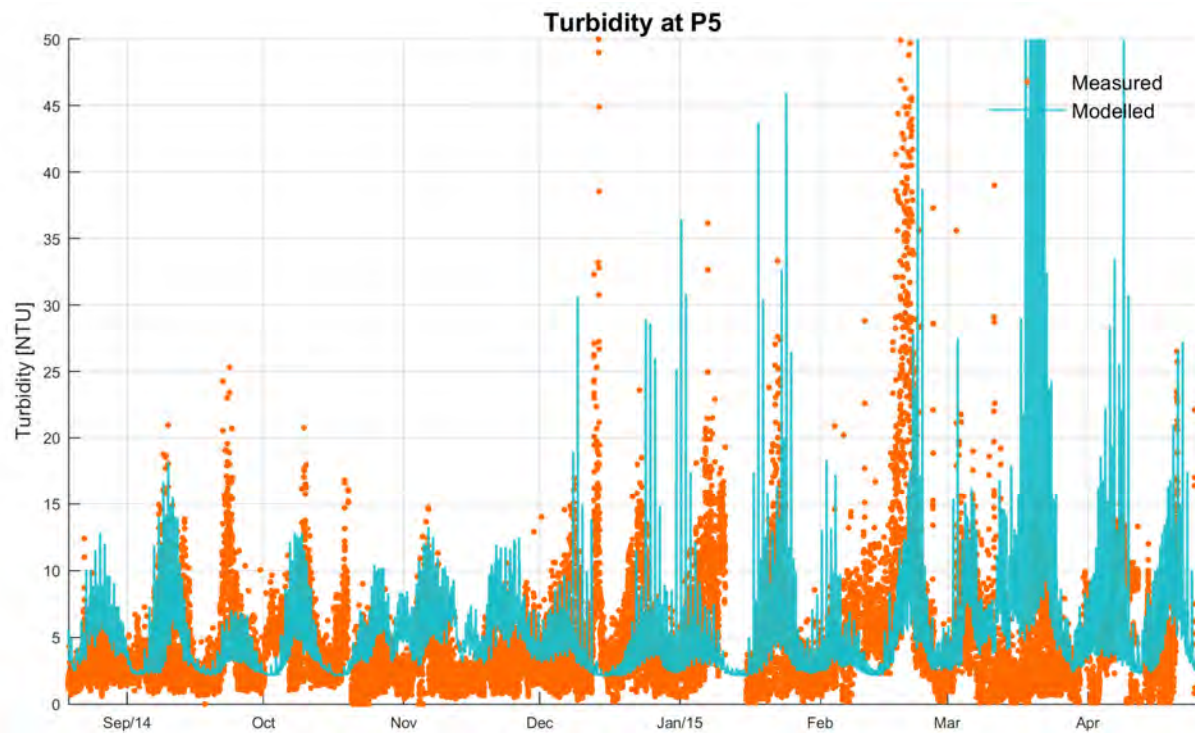


Figure 2-39 Ambient Turbidity Calibration Plots – Site P5

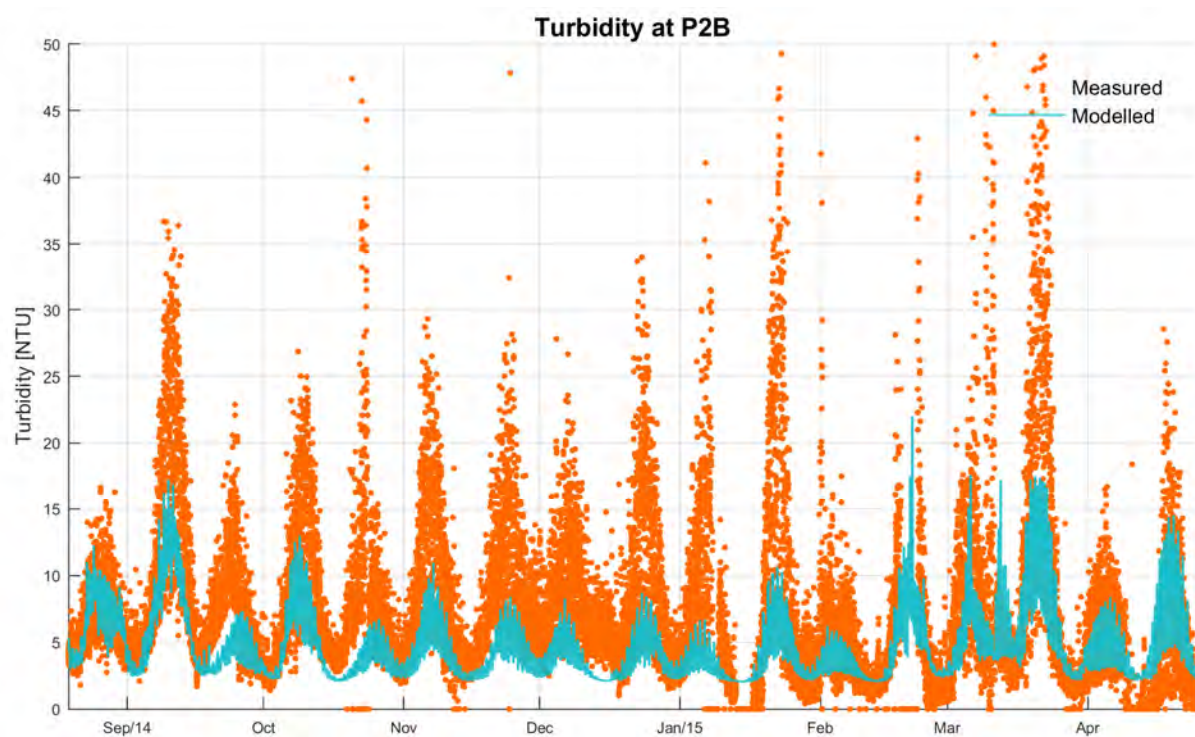


Figure 2-40 Ambient Turbidity Calibration Plots – Site P2B

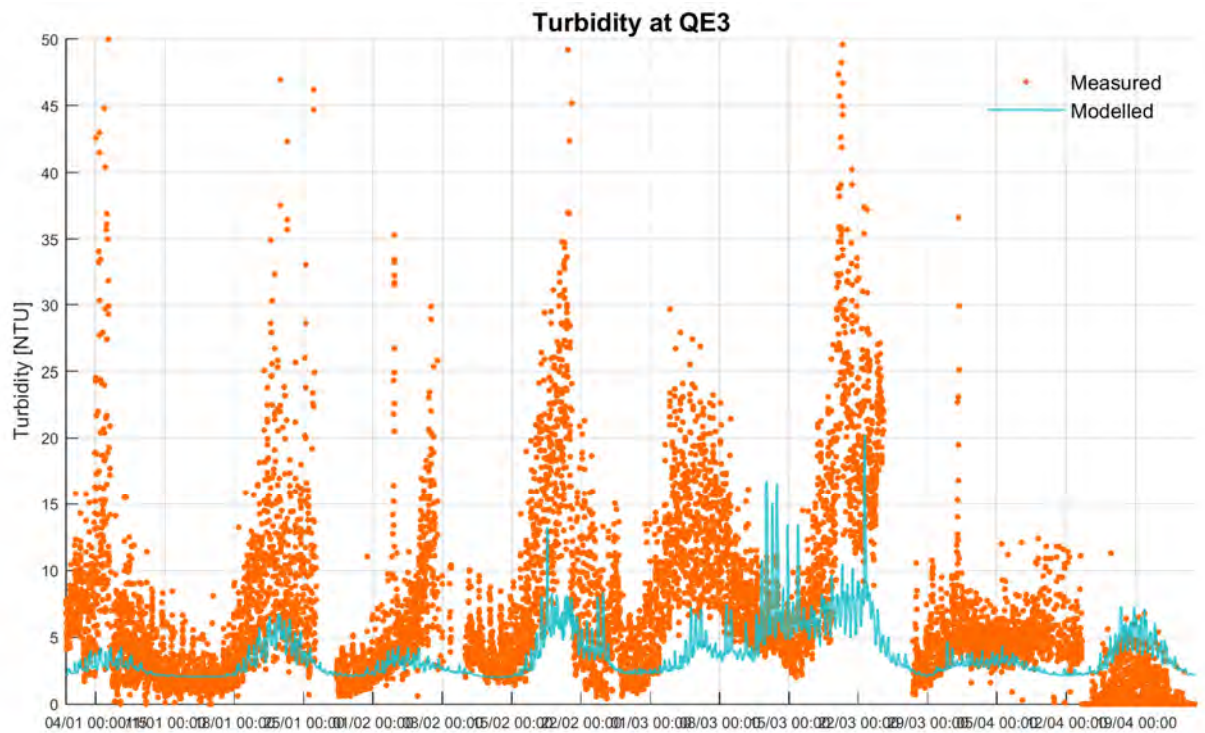


Figure 2-41 Ambient Turbidity Calibration Plots – Site QE3

3 Existing Hydrodynamics and Coastal Processes

3.1 Tidal Hydrodynamics

An understanding of the tidal hydrodynamics is important because of its controlling influences on flushing and sediment transport processes. The Channel Duplication Project involves dredging and reclamation works. As such, it is necessary to understand the potential direct impacts these may have on tidal hydraulic processes as well as any follow-on effects for water quality, sedimentation and associated ecological implications.

The extent of the tidal hydraulic system considered in the context of this study includes the whole of the estuarine waters of Port Curtis and connected rivers/inlets as described above. Tides propagate into the Port from the south (south of Facing Island), east (between Facing and Curtis Islands) and the north (from Keppel Bay into The Narrows). This results in complex interactions with the tidal waves meeting near the centre of The Narrows – a ‘null’ point.

The Calliope and Boyne Rivers, as well as Auckland and South Trees Inlets, discharge into the central section of the Port. Further to the south are the connected waterways of Colosseum Inlet, Seven Mile Creek and Rodds Bay, while Graham’s Creek and a number of smaller tributaries connect to The Narrows.

The Port area also contains a number of smaller islands and has extensive areas of intertidal flats, which become exposed at low water. For very low tides, some areas reduce to several narrow meandering channels. There are also very large intertidal mangrove and saltpan areas in Port Curtis, which are inundated at higher tide levels. The large tidal range and extensive intertidal banks result in changes to the available storage areas at different tidal elevations. These changes cause the estuary to exhibit non-linear behaviour for tides of large range (i.e. tidal flow velocities and rate of rise and fall vary greatly depending on the extent of coverage of the salt pans and mangroves).

Tidal variations in Port Curtis and adjoining areas are reasonably well understood from extensive recordings and analyses by the Queensland Government, and accurate predictions are available for Standard and Secondary Ports in the region. The tidal times, heights and planes are published by MSQ for the Standard Port of Gladstone Harbour at Auckland Point in the publication ‘Queensland Tide Tables 2015’ (MSQ 2014). The tidal planes for the Standard Port and other secondary locations within Port Curtis are presented in Table 3-1 as heights above the local Lowest Astronomical Tide (LAT) level at each location.

It can be seen that the mean spring tidal range for Gladstone is 3.24 m, the mean neap tidal range is 1.54 m and the maximum tidal range is 4.69 m. The tidal range amplifies within the Port; the range at Fisherman’s Landing is approximately 6% greater than at Gladstone (Auckland Point) and the range at Gatcombe Head is 11% smaller than at Gladstone (Auckland Point).

Table 3-1 Gladstone Region Tidal Planes (m LAT)

Tidal Plane	Fisherman's Landing	Gladstone (Standard Port)	South Trees Wharf	Gatcombe Head
Latitude	-23° 47' S	-23° 50' S	-23° 51' S	-23° 53' S
Longitude	151° 11' E	151° 15' E	151° 19' E	151° 22' E
Highest Astronomical Tide (HAT)	5.12	4.83	4.63	4.29
Mean High Water Springs (MHWS)	4.20	3.96	3.80	3.45
Mean High Water Neaps (MHWN)	3.30	3.11	2.99	2.71
Mean Level (ML)	2.41	2.34	2.20	2.08
Australian Height Datum (AHD)	2.43	2.268	2.21	Not applicable
Mean Low Water Neaps (MLWN)	1.66	1.57	1.51	1.37
Mean Low Water Springs (MLWS)	0.76	0.72	0.69	0.56
Lowest Astronomical Tide (LAT)	0.00	0.00	0.00	0.00

Due to the large tidal storage areas and the amplification effect on water levels, good tidal flushing and high tidal velocities generally exist within the main channels of Port Curtis. Typically observed spring tide velocities within dredged shipping channels are up to a maximum of approximately 2.0 m/s in some local areas. Due to the strong spring tidal currents, the tidal flows in the estuary are usually well mixed and stratification is not significant except during periods of major flooding. Spatial plots of typical current fields in the vicinity of the proposed dredging works during spring flood and ebb tidal phases are shown in Figure 3-1. The highest velocities are typically found in the vicinity of the shipping channels, and can be especially high in the vicinity of Gatcombe and Golding Cutting Channels. Ebb tide velocity magnitudes tend to be slightly higher than flood tide velocity magnitudes for a given tidal range. Within the channels the current direction is generally parallel to the channel. The tidal velocities are highest at the southern end of the Gatcombe Channel, in the vicinity of Gatcombe Head. Further outside the Port, the flow fans out over East Banks and velocity magnitudes in the channel are lower.

Tidal velocities during neap tidal periods are much lower. This spring-neap variability can be seen in the time series of the water velocity at the ADCP data collection locations (shown in Figure 2-7) in Figure 2-17 to Figure 2-22. The data collection locations ADCP 3 and ADCP 4 are located closest to the proposed dredging operations. Velocity magnitudes, pre-dominantly tidal, of up to 1.4 m/s were recorded at location ADCP 3 and up to 0.9 m/s at ADCP 4.

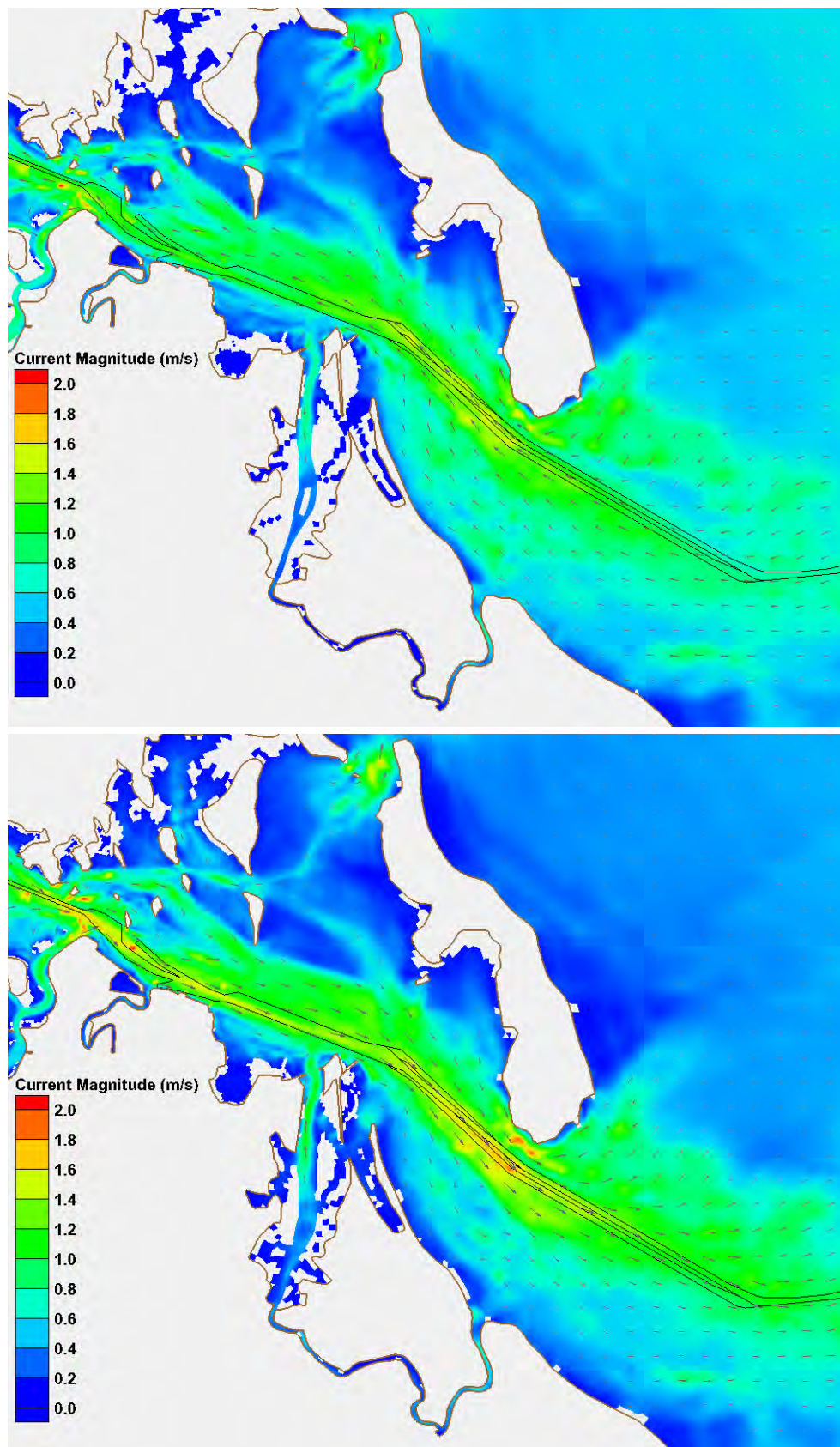


Figure 3-1 Example Spring Tidal Currents; Flood (Top), and Ebb (Bottom)

3.1.1 Existing Hydrodynamics in the Vicinity of the Western Basin Reclamation Area

Baseline water level measurements in the vicinity of the WB reclamation area were recorded at the MSQ gauge at Fishermans Landing (see Figure 2-7 for location). Data collected following completion of construction of the existing WB reclamation is provided in Figure 3-2.

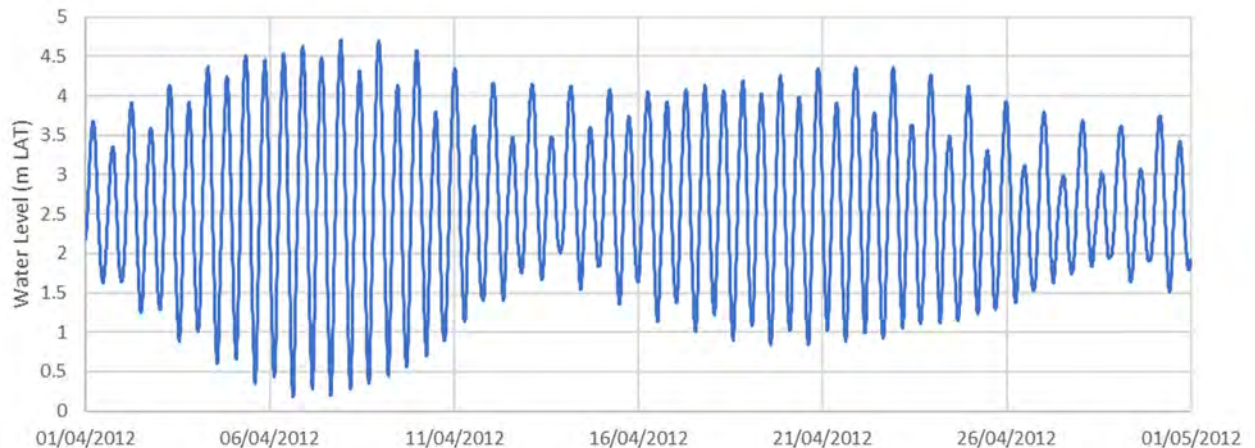


Figure 3-2 Recorded Water Level at Fishermans Landing Tide Gauge (MSQ)

Measured current speeds and directions adjacent to the existing WB reclamation during ebb and flood spring tides are provided in Figure 2-27. The measurements indicate typical flood tide depth-averaged current speeds during spring tides of around 0.8 m/s, and ebb tide current speeds during spring tides of around 1 m/s. A long term ADCP deployment was undertaken in 2009, and depth-averaged current measurements are shown in Figure 3-3.

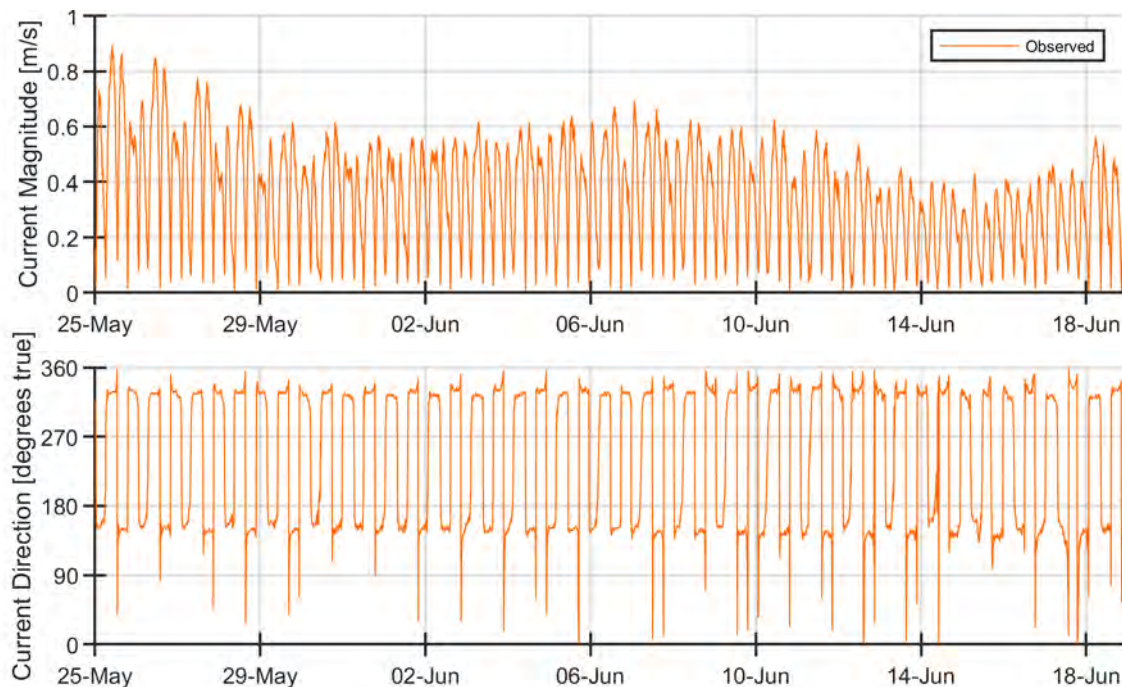


Figure 3-3 Measured Depth-Averaged Currents at ADCP Western Basin (Location Shown in Figure 2-7)

3.2 Extreme Water Levels

Water levels at the coast during cyclones may be substantially higher than normal tides due to storm surge effects. Storm surges are increases in water level caused by onshore wind stresses and reduced atmospheric pressure.

The storm tide level is the result of tide plus surge. The surge may peak at any stage of the tidal cycle. Hence abnormally high storm tide levels may result from extreme surge peaks coinciding with moderate to high tides, or moderate surges coinciding with high tides. The probability of an extreme surge peak coinciding with a spring high tide is low, especially in areas of high tide range.

A comprehensive study commissioned by the Queensland Government (James Cook University, 2004) examined storm tide vulnerability and potential increases in sea level from climate change and more intense cyclonic effects on coastal communities. The study report is available via the Queensland Government Long Paddock website:

<https://legacy.longpaddock.qld.gov.au/about/publications/vulnerabilitytocyclones/stage3.html>

This study incorporated detailed modelling on a nearshore grid of approximately 550 m, which extended into Port Curtis. The predicted storm tide levels in the region for the year 2003 are provided in Table 3-2 for various recurrence intervals excluding wave set-up and climate change effects. These levels are also provided in the DTMR guideline *Storm Tide – Issues for Design of Road Infrastructure in Coastal Areas*, (DTMR 2014).

Table 3-2 Peak Storm Tide Levels (Year 2003)

	Storm Tide Level (m LAT)		
	100 year ARI ¹	500 year ARI	1,000 year ARI
Gladstone	5.09	5.78	6.07
1. Average Recurrence Interval			

The above storm tide levels do not contain provisions for sea level rise (SLR) due to climate change effects, other climate influences or wave set-up and run-up. Wave set-up and run-up only occur near or at the shoreline and therefore do not influence levels in the shipping channel.

The ocean hazards assessment study (James Cook University, 2004) also examined the potential implications for storm tide statistics of three specific climate change scenarios:

- (a) Combined effect of an increase in Maximum Potential Intensity (MPI) of 10% and a poleward shift in tracks of 1.3 degrees.
- (b) Increase in frequency and intensity of tropical cyclones of 10%.
- (c) Mean SLR of 0.3m.

The mean SLR component (c) has an almost linear effect on the resultant storm tide levels while the 10% increase in cyclone frequency and intensity (b) has negligible impact. The combined increase in intensity and poleward shift in tracks (a) becomes increasingly significant with large return periods. The storm tide levels predicted with the combined climate change scenarios are presented in Table 3-3.

Table 3-3 Peak Storm Tide Levels (Combined Climate Change Scenarios 50 Year Planning Period from 2003)

Location	Storm Tide Level (m LAT)		
	100 year ARI	500 year ARI	1,000 year ARI
Gladstone	5.60	6.45	6.78

The report emphasised that the chosen values in the climate change scenarios are not necessarily endorsed, although care has been taken to propose reasonable values. The intention was to demonstrate the sensitivity of the storm tide frequency curves to climate change scenarios. It should be further noted that the value of 0.3 m mean SLR was derived for a 50-year planning period from 2003 (the SLR allowance was based on recommendations in the now superseded IPCC third assessment report). The modelled sea level rise predictions from the most recent IPCC report presented in AEIS Chapter 11 (climate and climate change assessment) are consistent with this value over that 50-year planning period.

3.3 Wave Climate

Waves are important drivers of sediment dynamics both within the estuary and in offshore areas. Wave-related bed shear stresses can resuspend sediment that has been deposited on the seabed, enabling subsequent transport of the sediment by tidal currents.

Facing and Curtis Islands effectively protect the inner Port areas from ocean-generated sea and swell waves. As such, the main Port berths are within a sheltered estuarine environment and only exposed to locally generated waves within Port Curtis. The largest fetch lengths within the Port are aligned to the southeast to northwest axis. These fetch distances are all relatively short and confined to less than 10 km.

The outer harbour and offshore areas are exposed to larger sea and swell waves. The dominant incident wave direction is from the north-east and east, and the wind direction is mainly north-easterly to south-easterly with the strongest winds coming from the east. The long term wind rose at the Gladstone Radar BoM station and the long term wave rose at the Gladstone Waverider Buoy are provided in Figure 3-4. Analysis of the year-by-year wave roses indicates that inter-annual variability is much smaller than the seasonal variation in the wave climate.

Numerical modelling was also used to describe the prevailing wave climate and assess the potential impact of the proposed Channel Duplication Project activities. Figure 3-5 shows an example of model output for a relatively energetic easterly incident wave condition, illustrating the effective protection that the Port is afforded by the presence of Facing Island and Curtis Island.

The measured wave climates at each of the ADCP locations shown in Figure 2-7 are shown in Figure 3-6 to Figure 3-9. At ADCP 1 there is significant exposure to energetic waves, predominantly from the east northeast. ADCP 2 is also exposed to waves from the north northeast to east northeast, however the incident wave energy propagating from these directions is lower than at ADCP 1 due to shoaling on the East Banks (located between ADCP 1 and ADCP 2). Sites ADCP 3 and ADCP 5 receive much lower levels of wave energy due to their sheltered locations behind Facing Island. Site ADCP 4 is exposed to waves from the east northeast to east southeast, however the energy is significantly reduced due to shoaling. The wave energy at ADCP 6 is similar

to that at site ADCP 2, with waves predominantly from the east northeast to east southeast. The wave energy at the ADCP Western Basin location is low due to the sheltered location.

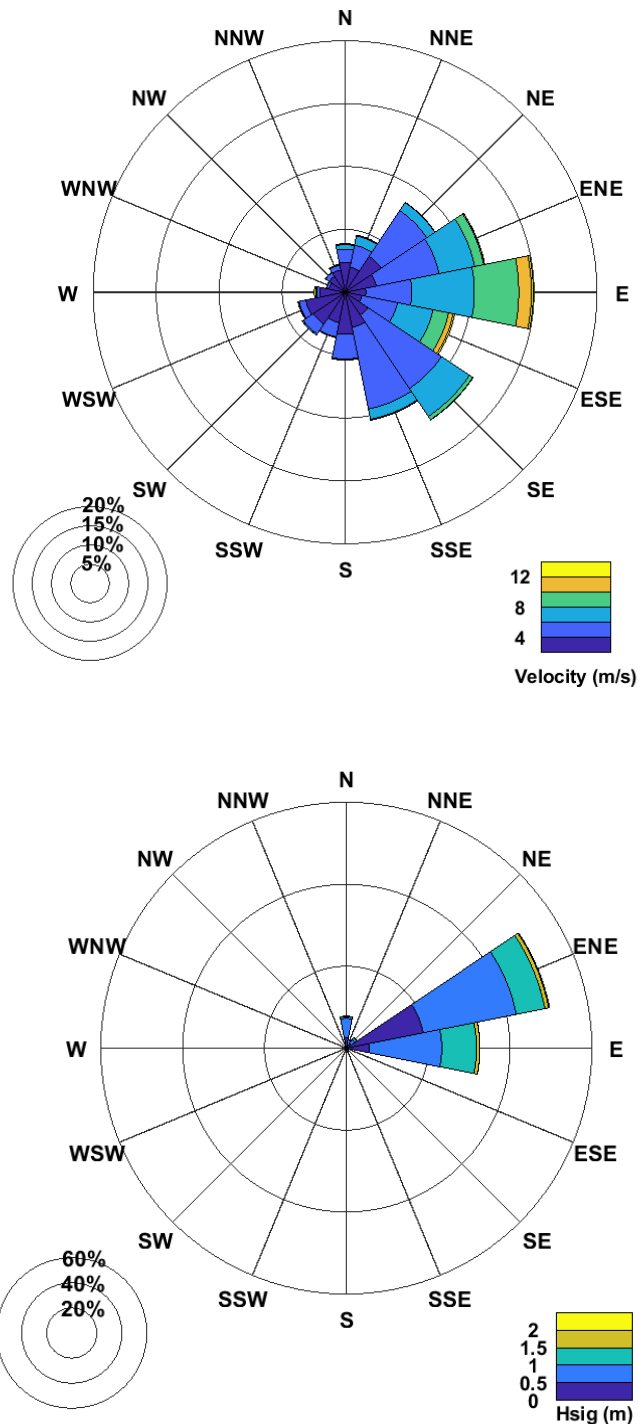


Figure 3-4 Long Term Wind Rose (1994-2014) at Gladstone Radar (Top) and Wave Rose (2010-2017) at the Gladstone Waverider Buoy (Bottom) – Refer to Figure 2-7 for Locations

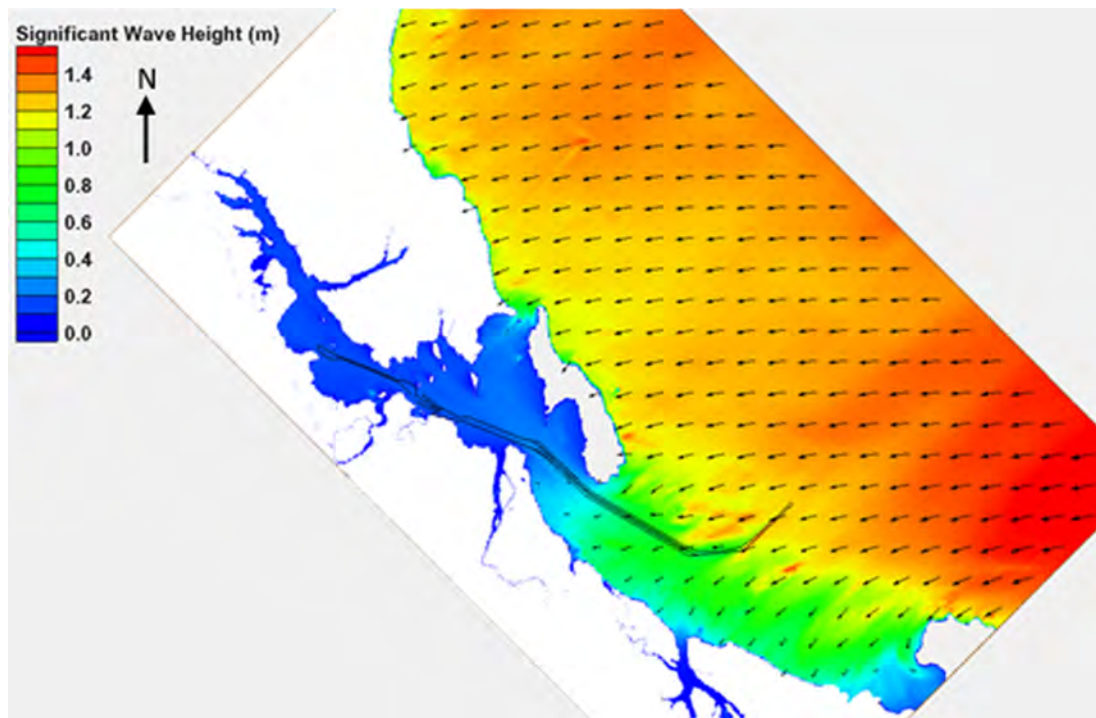


Figure 3-5 Example of Energetic Easterly Wave Conditions

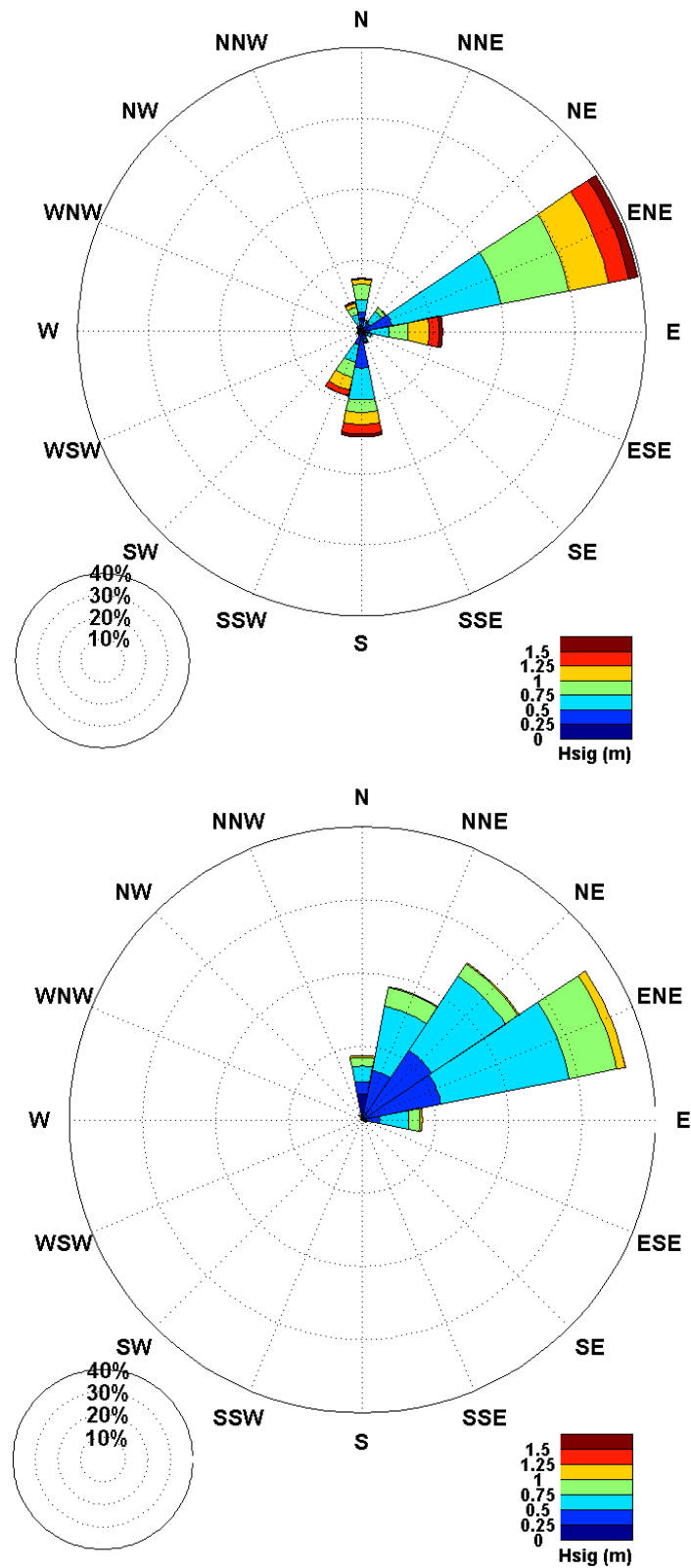


Figure 3-6 Wave Roses at ADCP1 (Top Panel, Jun-Sep 2014) and ADCP2 (Bottom Panel, Sep-Dec 2014)

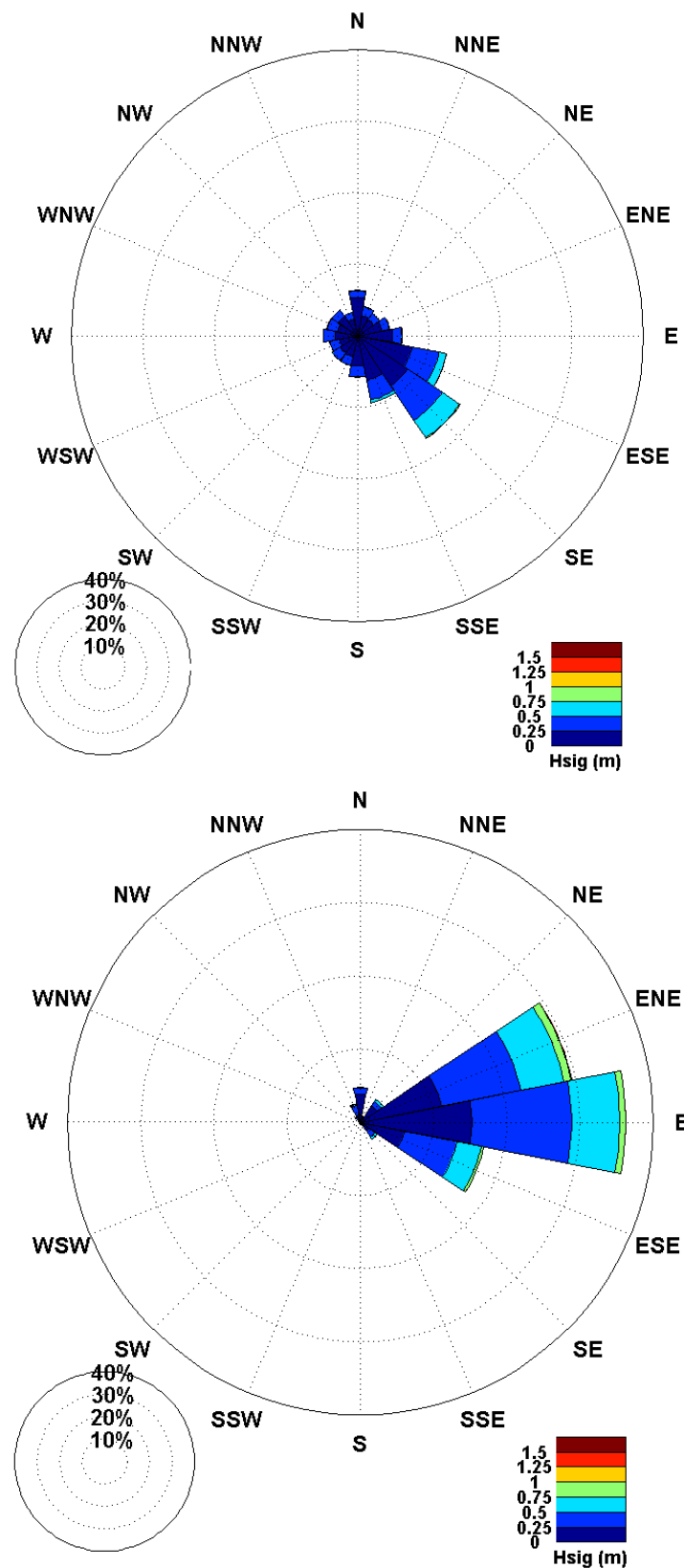


Figure 3-7 Wave Roses at ADCP3 (Top Panel, Jun-Sep 2014) and ADCP4 (Bottom Panel, Jun 2014 – Jul 2015)

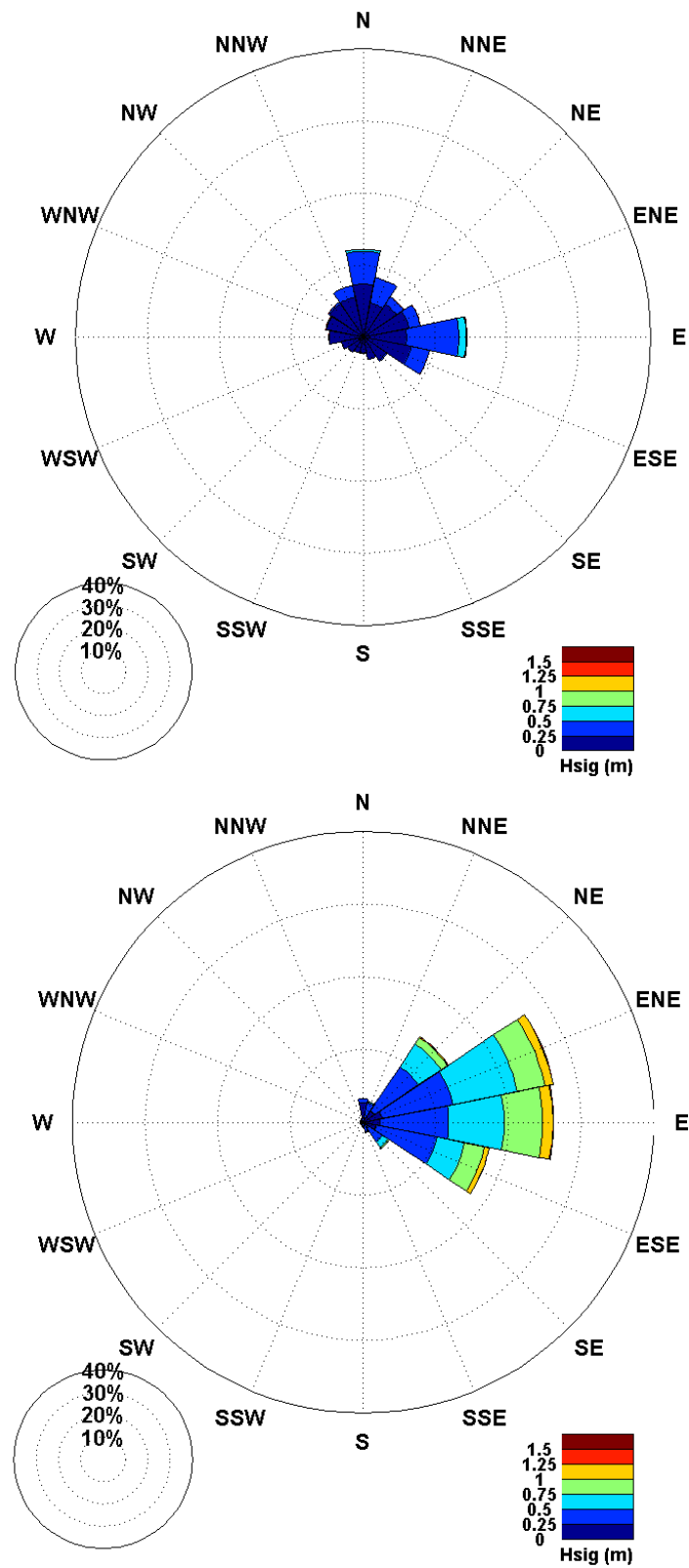


Figure 3-8 Wave Roses at ADCP5 (Top Panel, Sep-Dec 2014) and ADCP6 (Bottom Panel, Jun-Sep 2014)

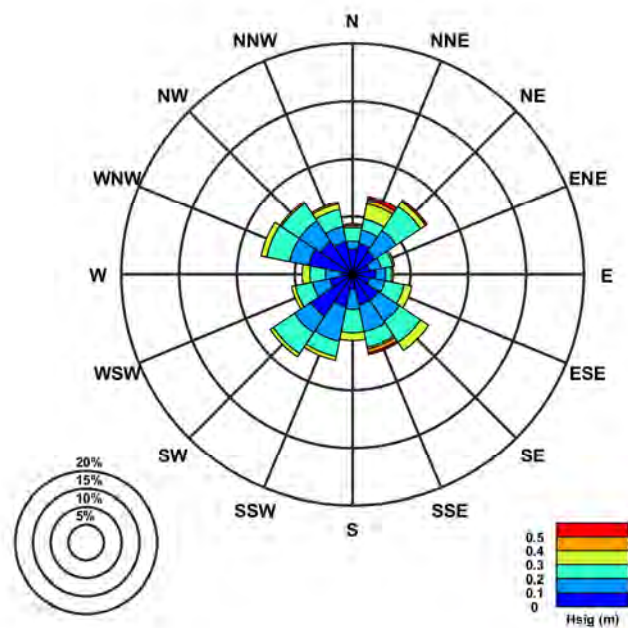


Figure 3-9 Wave Rose at ADCP Western Basin (Jun 2009)

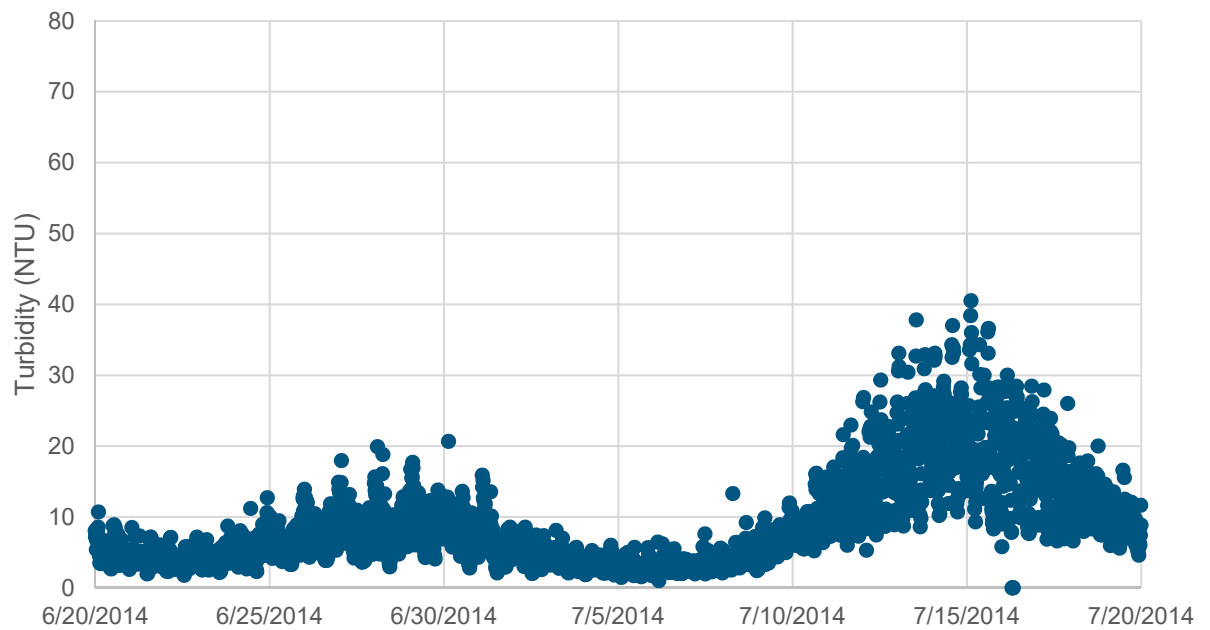
3.4 Sediment Dynamics

The energetic macro-tidal hydrodynamic conditions in Port Curtis play an important role in the context of natural bed remobilisation processes and associated patterns in TSS concentrations. Within the Port, the bed shear stress associated with the tidal currents is generally the dominant driver of sediment resuspension and wave-related bed shear stress is of secondary importance. In the outer reaches of the Port, and in offshore areas, wave energy is higher and tidal velocities are lower and therefore the wave-related bed shear stress is a much more significant driver of resuspension processes.

Measured turbidity within the Port shows substantial variation in turbidity levels over each tidal cycle as well as significant variation between neap tidal and spring tidal periods. The typical spring-neap variation in turbidity levels is shown in Figure 3-10. There is also substantial spatial variation in turbidity levels throughout the Port, particularly during spring tidal periods. Figure 3-11 shows an example of modelled total (depth-summed) sediment fluxes on an ebbing spring tide (top panel) and flooding spring tide (bottom panel). It is apparent that there is high sediment transport potential in the vicinity of the dredging operation during spring tides, particularly in the more northerly Gatcombe Channel.

The sediments in the vicinity of the existing passing channel to be dredged are a mixture of gravels, sands, silts and clays. The surface sediments in the main channels of the Port where tidal velocities are high are typically dominated by coarser fractions with the finer particles having being naturally swept away. The shallower intertidal areas are a mixture of sands and silts with fine soft silts dominating in the lower current/wave energy areas.

The contribution of local catchments to the overall sediment budget of the Port is relatively minor. A quantitative sediment budget for Queensland ports (BMT, 2018) estimated that the Calliope and Boyne rivers contribute approximately 97,000 tonnes per year of sediment to the Port, while the natural resuspension of inner-shelf sediment deposits is approximately 15,400,000 tonnes per year. The net longshore transport of coastal sediment is to the north. The shipping channels within the Port act as a sediment sink because they are generally deeper than the surrounding seabed and are less exposed to wave and current energy. Approximately 260,000m³ of material is removed from the shipping channels annually by maintenance dredging. The relocation of port maintenance dredging material to the placement area located within the active sedimentary system maintains ongoing transport of sediment along natural sediment pathways, with maintenance dredge material gradually re-assimilated into the ambient sedimentary system from which it originated.



**Figure 3-10 Example Variation in Turbidity Within Port Curtis
(at Site P2B, refer to Figure 2-7 for Location)**

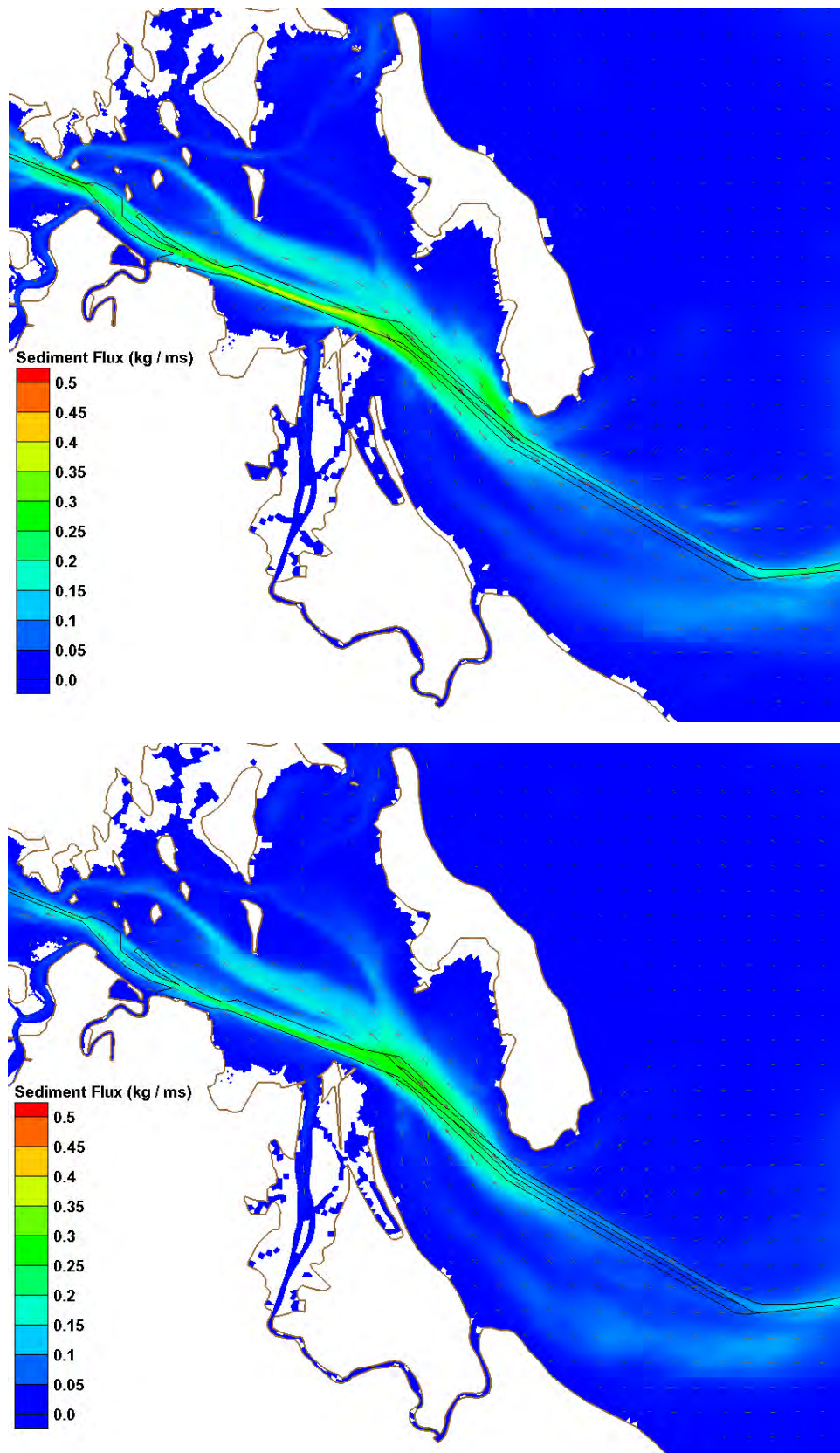


Figure 3-11 Example Total Sediment Fluxes (kg/s per metre) for Ebb Spring Tide (Top) and Flood Spring Tide (Bottom)

3.5 Coastal Processes

Shoreline coastal processes within the study area are influenced by the local wave climate as well as the tidal hydrodynamics and sediment dynamics.

3.5.1 Western Basin Expansion Reclamation Area

The wave climate in the vicinity of the existing Fisherman's Landing and Western Basin (WB) reclamation area is generally benign and the shoreline is characterised by fringing mangroves and a flat intertidal zone. Aerial photography does indicate some small sandy beach ridges which are likely composed of silty sand. Figure 3-12 shows aerial photographs from 1959 (top panel) and 2015 (bottom panel). The major differences in the two photographs are associated with the WB reclamation works, including construction of the reclamation area and the LNG facilities on Curtis Island. Other changes include clearing and trenching activities associated with construction of the QCLNG pipeline. There are minor changes to the extent of mangrove cover, but otherwise the shoreline alignment and character behind the existing WB reclamation area appears largely unchanged up to this point. The hydrodynamics, wave climate and sediment dynamics on the intertidal flat have been modified due to the construction of the reclamation area and, over time, this could be expected to cause changes in the bathymetric features and ecology of the intertidal area (e.g. may promote siltation and mangrove growth).



Figure 3-12 Western Basin Aerial Photographs – July 1959 (Top) and July 2015 (Bottom)
(Sources: Queensland Government, Gladstone Ports Corporation)

3.5.2 Boyne Island Shoreline

The Boyne Island shoreline is approximately 2 km to 4 km to the west of the Gatcombe Channel, with the shoreline exposed to higher energy wave conditions than the inner Port because it is open to the ocean to the east. The shoreline is a sandy beach with a relatively flat offshore profile. Aerial photographs taken in 1959 and 2015 are shown in Figure 3-13. It is apparent that there have been some subtle shifts in the alignment of the beach but the overall character remains unchanged. The dominant easterly incident wave direction is likely to generate a net northerly longshore sediment transport along the beach. On close inspection of the 1959 and 2015 photographs it is apparent that the beach has prograded in a number of locations over the intervening years, including development of the small salient marked in Figure 3-13. It is expected that the net longshore transport of sandy sediment along this section of coastline is to the north.

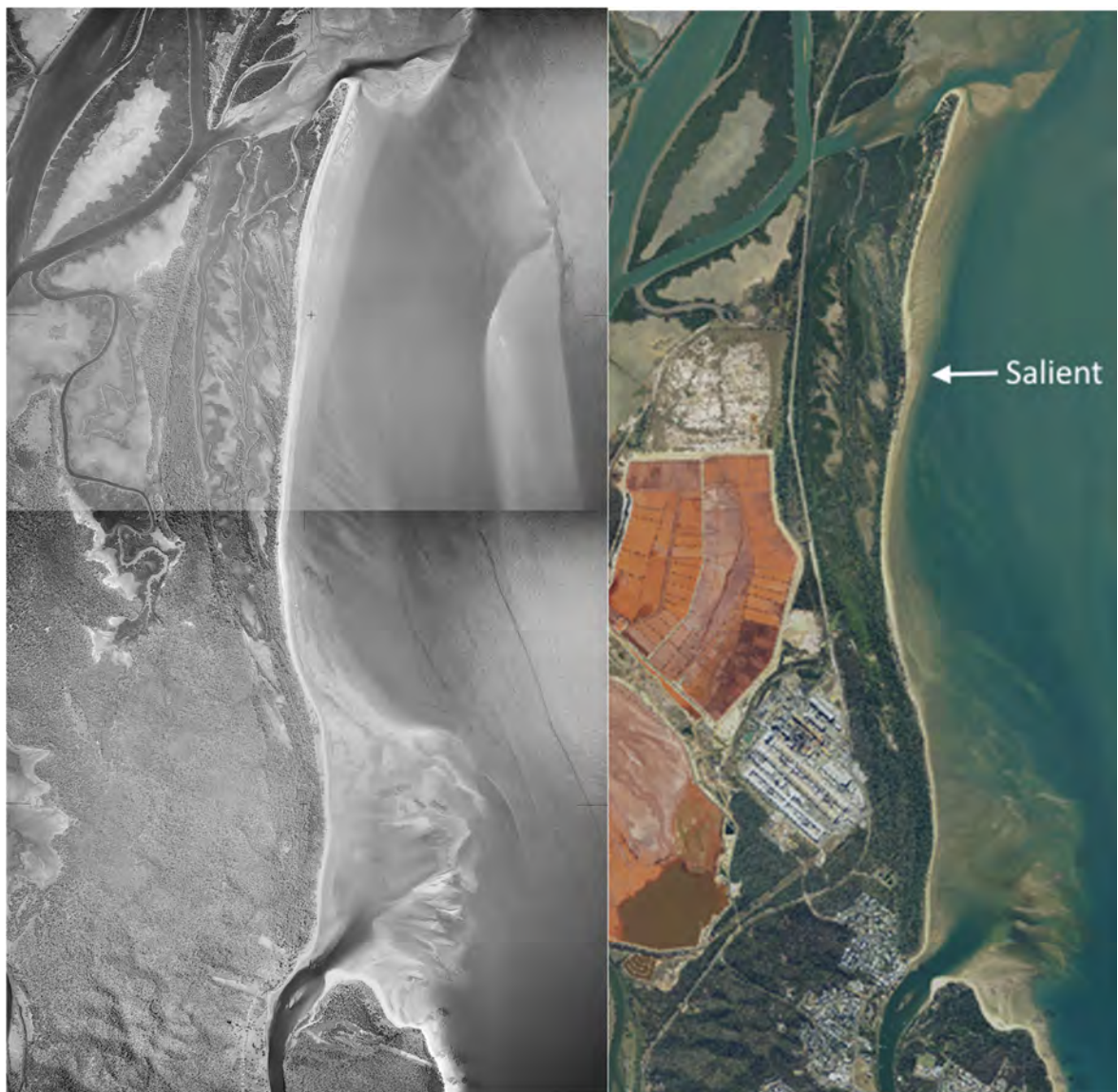


Figure 3-13 Boyne Island Shoreline – July 1958 (Left) and July 2015 (Right) (Sources: Queensland Government, Gladstone Ports Corporation)

3.5.3 Facing Island

The shoreline of Facing Island is characterised by rocky headlands and sandy beaches, with some areas of intertidal mudflats and mangroves on the inner (harbour) side. The beaches on the ocean side of the island are wider than the beaches on the inner side, and are exposed to a much more energetic wave environment. It is therefore expected that the beaches on the ocean side have a larger typical grain diameter than those on the inner side. Aerial photographs from 1959 and 2013 are shown in Figure 3-14. There is little visible change in the nature of the shoreline, except for the construction of a small boat harbour on the south-west corner of the island. There are significant increases in the extent of vegetation cover on dunes on the eastern side of the island.

It is acknowledged that the residents of Facing Island are concerned about ongoing siltation issues in the small boat harbour.

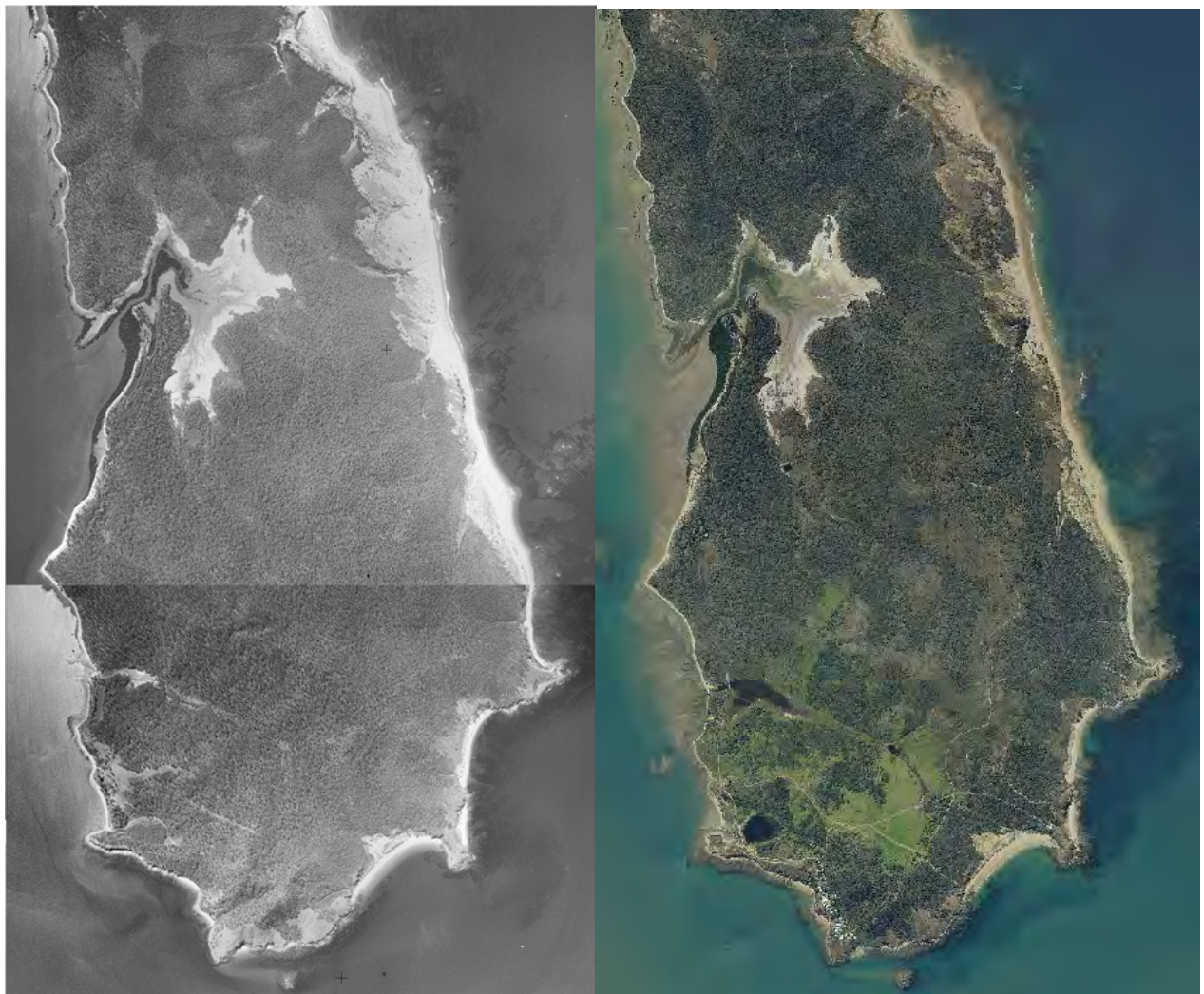


Figure 3-14 Facing Island Aerial Photograph – July 1959 (Left) and July 2015 (Right)
(Sources: Queensland Government, Gladstone Ports Corporation)

4 Hydrodynamics and Coastal Processes Impact Assessment

4.1 Scenarios Assessed

Two scenarios were assessed to determine potential impacts from Project activities to hydrodynamics and coastal processes, including:

- Base Case – Existing Port geometry, including existing LNG developments and completed WICT dredging.
- Project Channel Geometry Case – Base Case plus duplicated channels (refer Figure 4-1, design level of -16.1m LAT), the full proposed WBE reclamation areas (dredged material dewatering ponds), barge access channel to -7.0m LAT and barge unloading facility (refer Figure 4-2).

This section of the report considers potential long term changes to hydrodynamics and coastal processes due to construction of the Project. It should be noted that there are also ongoing changes caused by existing completed works that will continue for many years (particularly in the vicinity of recently completed work in the WB area).

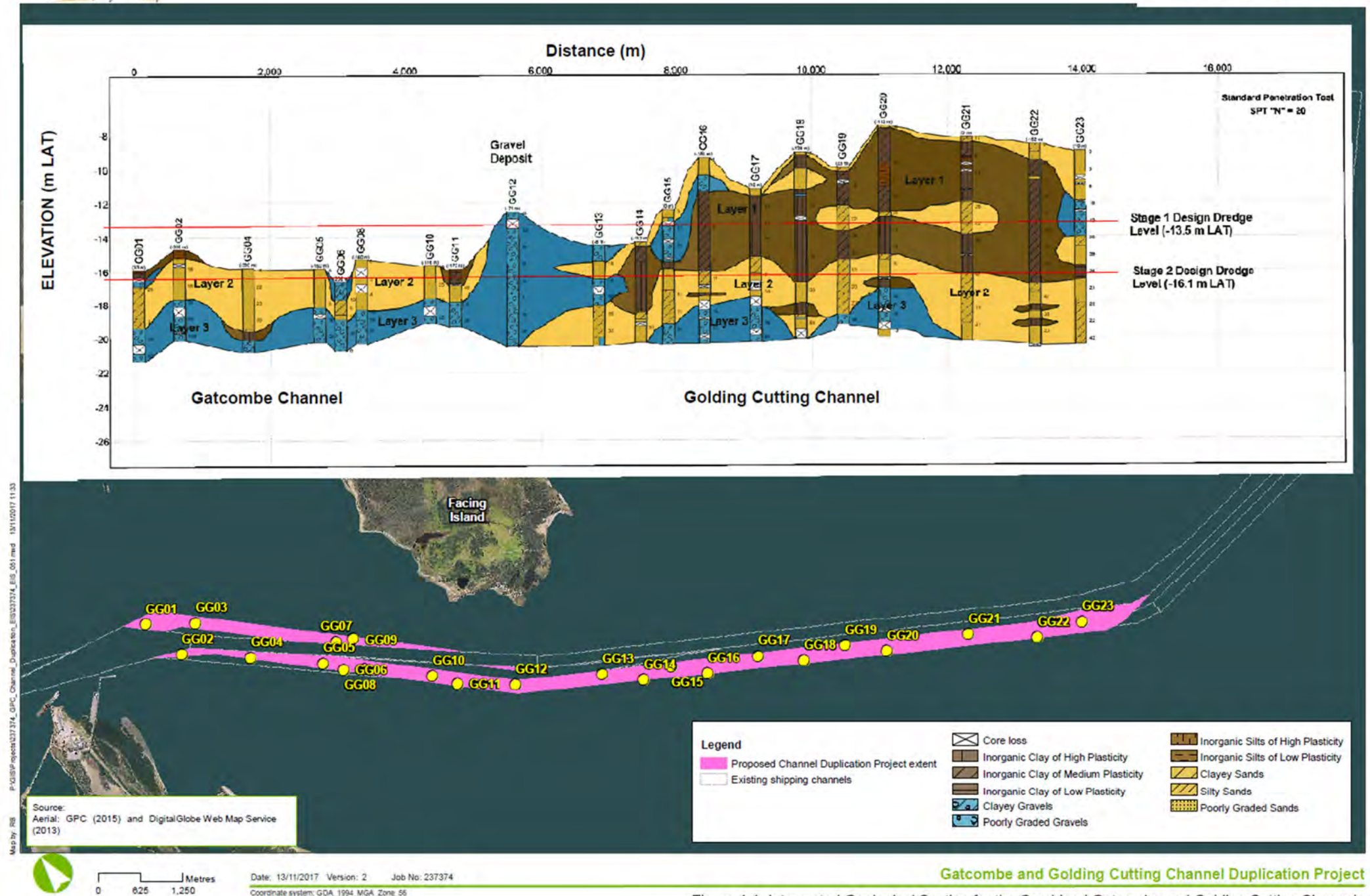
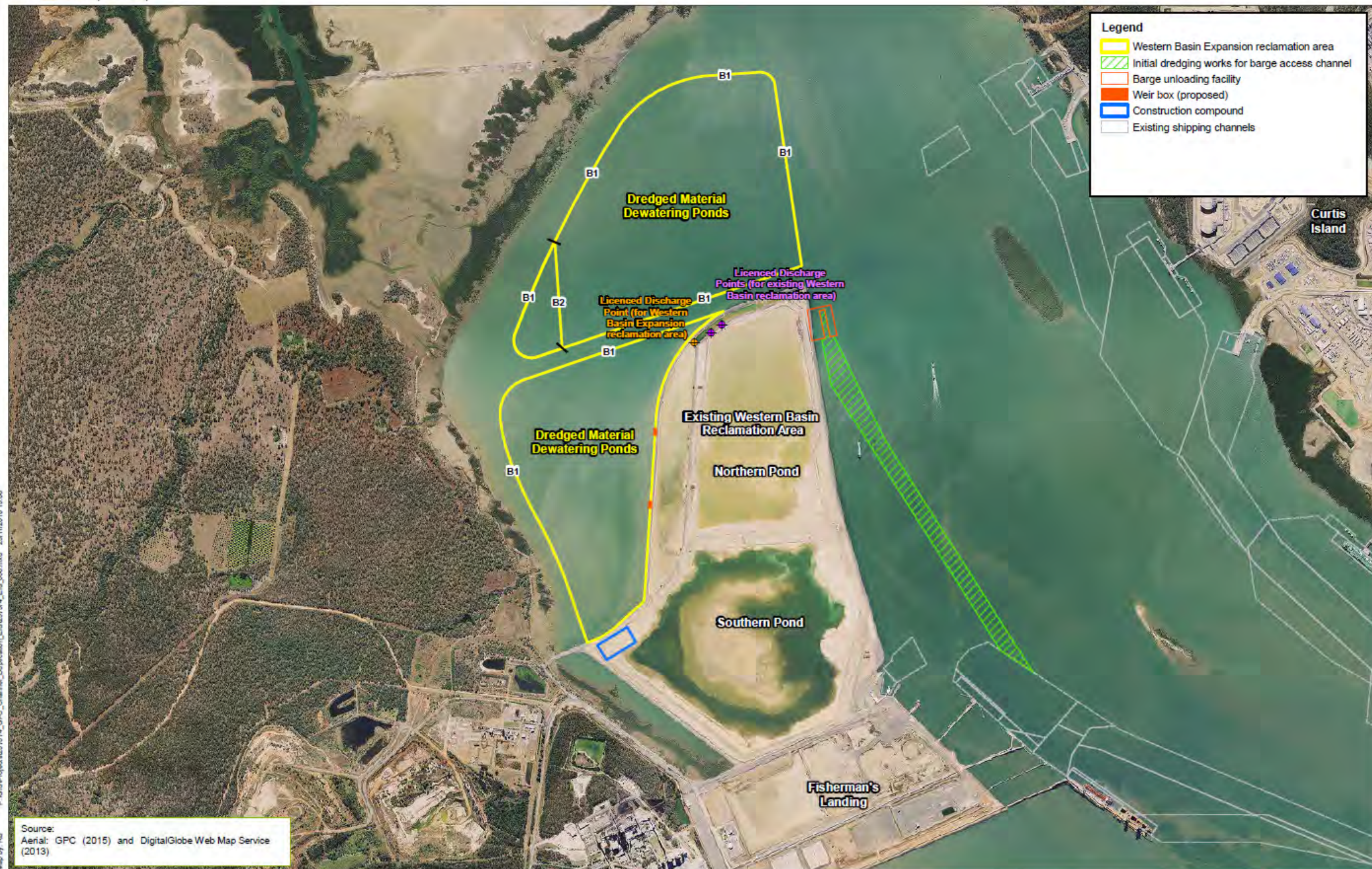


Figure 4-1 Interpreted Geological Section for the Combined Gatcombe and Golding Cutting Channels



0 255 510 Metres

Date: 23/11/2018 Version: 16 Job No: 237374
Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 4-2 Western Basin Expansion Reclamation Area

The TUFLOW FV mesh was modified and refined to incorporate the design of the proposed reclamation areas and the barge unloading facility. Figure 4-3 illustrates the bathymetry and mesh structure in the vicinity of the WBE reclamation area.

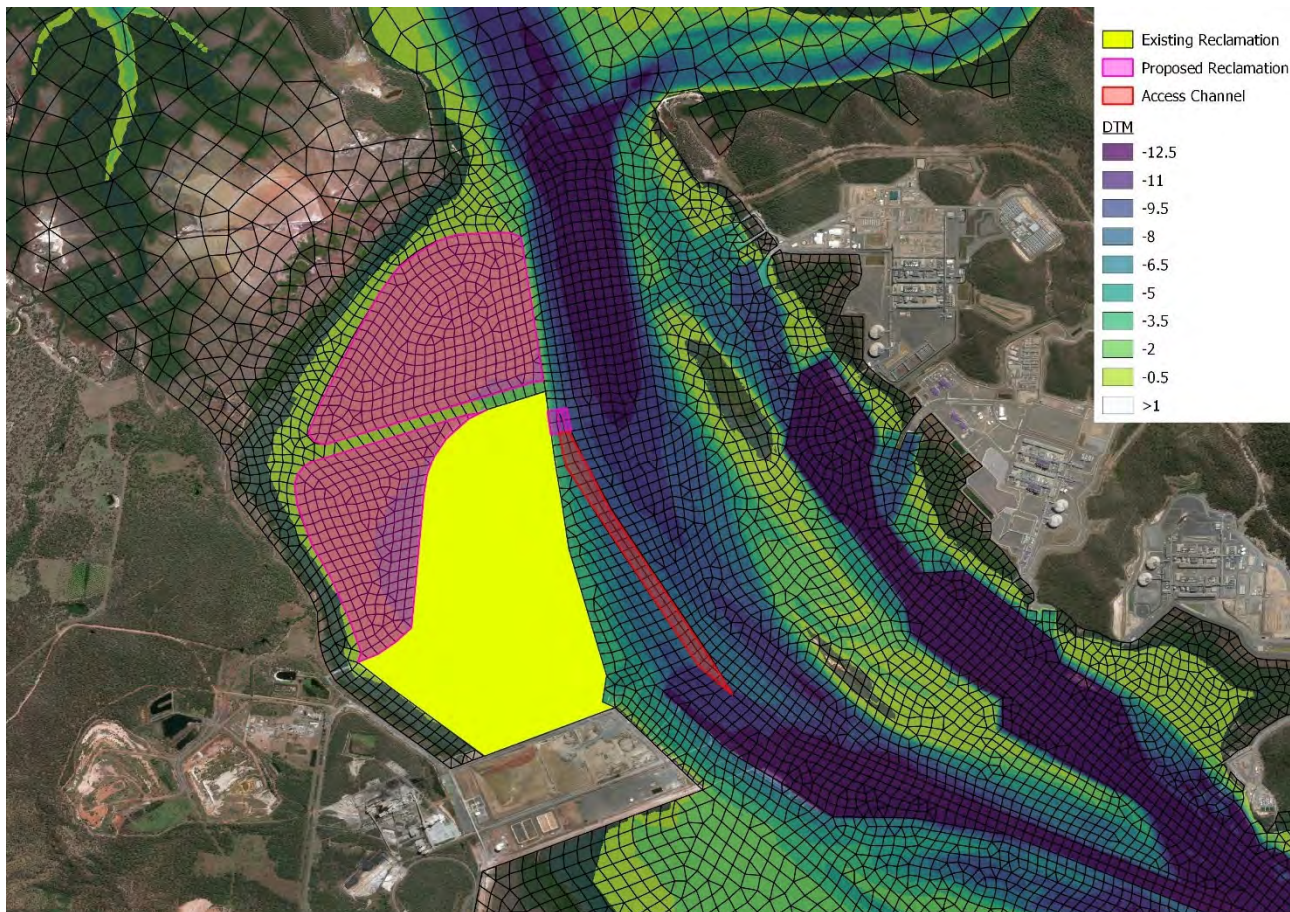


Figure 4-3 Western Basin Expansion Reclamation Area – Bathymetry and Mesh Structure

4.2 Assessment Period

The model was run for the period 25 June 2014 to 1 July 2015 to determine the potential hydrodynamic and coastal process impacts. The wind rose for the assessment period is compared to the long term wind rose in Figure 4-4 using data from the BoM for the 'Gladstone Radar' station. The wave rose for the assessment period is compared to the long term wave rose in Figure 4-5 using data from the Gladstone Waverider Buoy. The wind and wave conditions during the assessment period were generally consistent with the long term conditions.

The major freshwater inflows included in the assessment period modelling are shown in Figure 4-6 (smaller catchment sources were also included in the modelling).

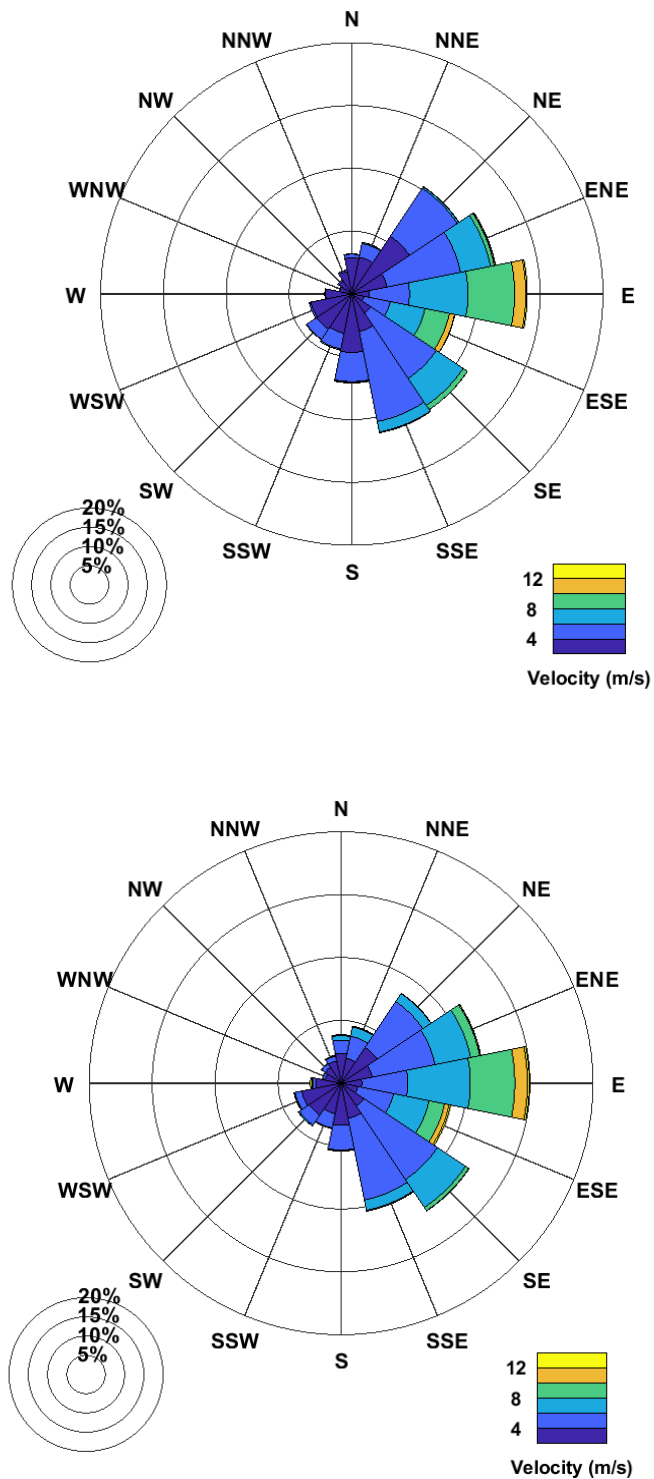


Figure 4-4 Assessment Period Wind Rose 1/7/2014 to 1/7/2015 (Top) and Long Term Wind Rose (Bottom) at Gladstone Radar (Top)

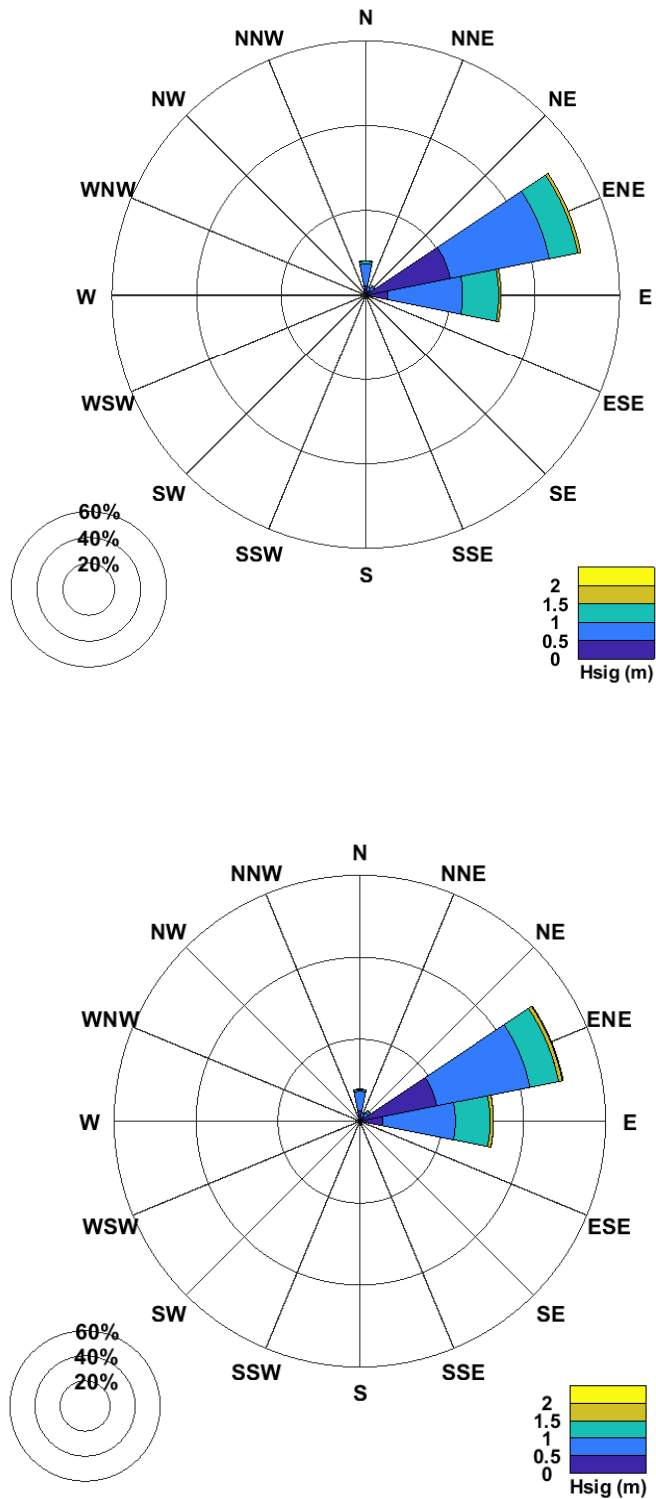


Figure 4-5 Assessment Period Wave Rose 1/7/2014 to 1/7/2015 (Top) and Long Term Wave Rose (Bottom) at the Gladstone Waverider Buoy

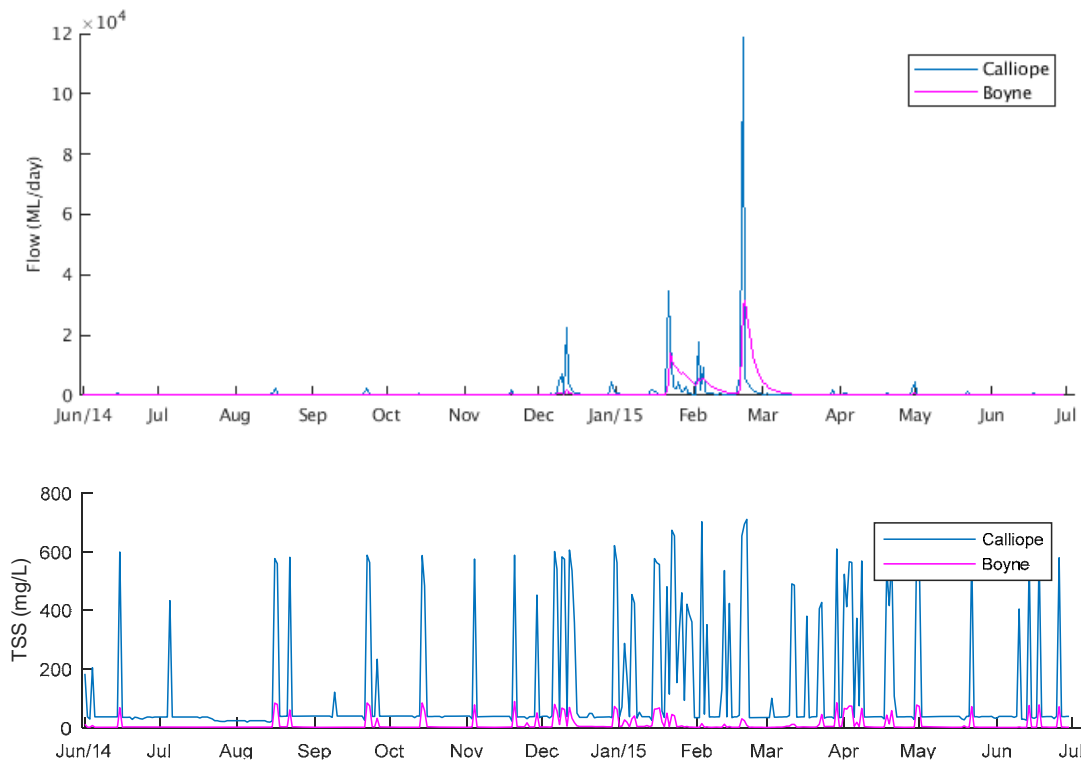


Figure 4-6 Major Freshwater Inflow Source Rates Included in the Assessment Period

4.3 Hydrodynamic Impact Assessments

4.3.1 Water Level Impacts

Model results indicate that the Project will have no effect on water levels at any point within the model domain. The modelled water level at Site P2B for the Base Case and the Project Channel Geometry Case is provided in Figure 4-7 as an example. The water levels in the two model runs are identical. Similar water level plots (showing no impact) are provided for tide gauge locations in Appendix F.

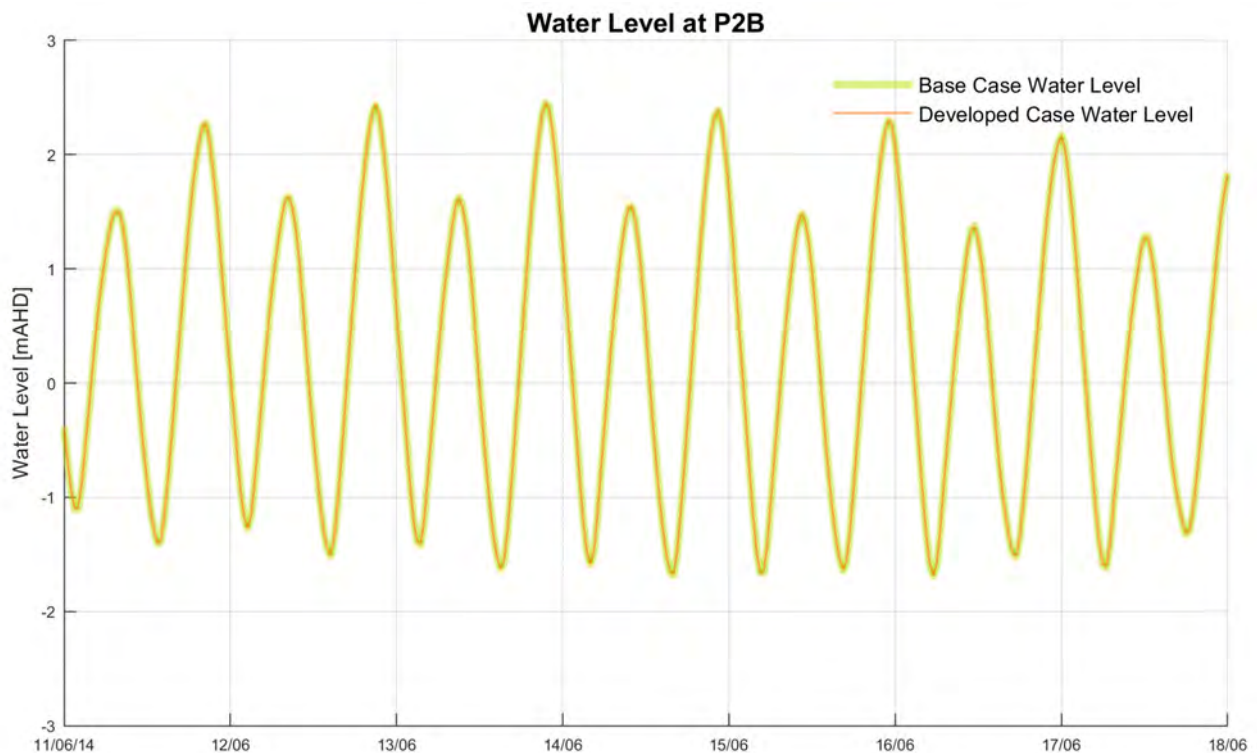


Figure 4-7 Water Level Impacts (No Change) at Site P2B (Refer to Figure 2-7 for Location)

4.3.2 Velocity Impacts - Western Basin Expansion Reclamation Area

The full construction of the proposed WBE reclamation area would create an additional reclamation area to the north of the expanded existing reclamation area and leave a narrow channel (~250m) along the existing shoreline and between the two reclamation areas (~100m) to allow for tidal flushing.

To illustrate the change in velocities, the maximum spring tide flood and ebb velocities were extracted for each point in the model domain during a 2-month simulation period. Figure 4-8 shows the peak ebb tide velocity patterns and magnitudes for the Base Case and the Project Channel Geometry Case, and the difference between them. Figure 4-9 shows the peak flood tide impacts. The model results indicate that there would be a reduction in velocity magnitudes immediately adjacent to the BUF and along the face of the northern part of the proposed WBE reclamation area. There would also be some increases in velocity magnitudes in the channels adjacent to the new reclamation areas. The modelled current speeds of up to 1.0 m/s in the Project Channel Geometry Case will need to be considered in bund-toe design.

4.3.3 Velocity Impacts - Duplicated Channel

The TUFLOW FV model was used to investigate velocity changes due to the proposed dredging of the Gatcombe and Golding Cutting bypass channels to a bed elevation of -16.1m LAT.

To illustrate the change in velocities, the maximum spring tide flood and ebb velocities were extracted for each point in the model domain during the 12-month simulation period. Figure 4-10 shows the peak ebb tide velocity patterns and magnitudes for the Base Case and the Project Channel Geometry Case, and the difference between them. Figure 4-11 shows the peak flood tide impacts. The model results indicate some slight reductions in velocity outside the channel in some areas, due to the reduced tidal prism, and within the deepened channels there are increases in some areas and decreases in others. None of the predicted velocity impacts are significant in magnitude in the context of the existing velocity magnitudes.

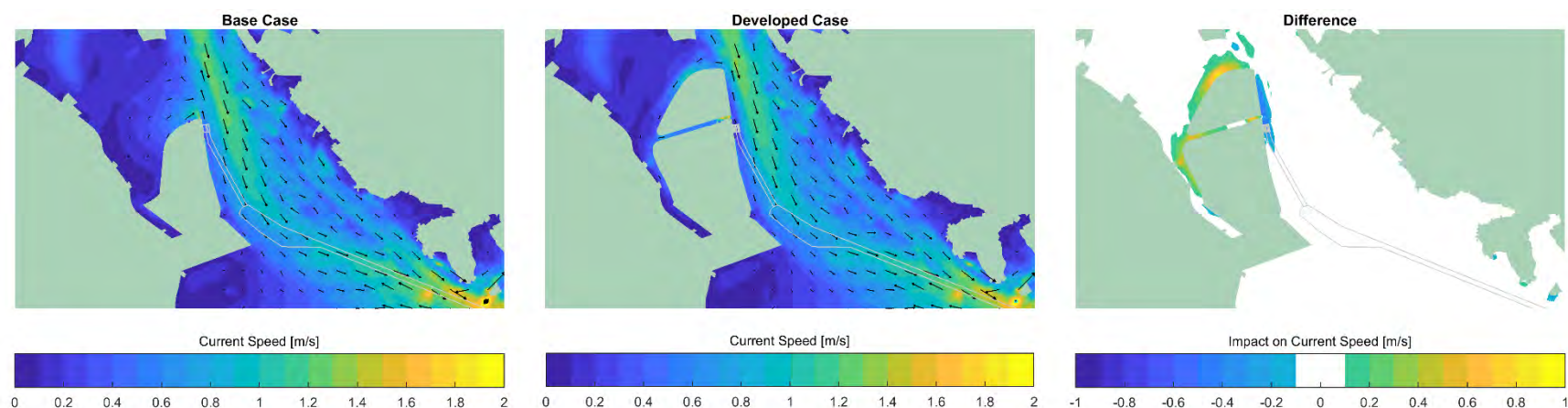


Figure 4-8 Ebb Tide Peak Spring Velocity – Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right)

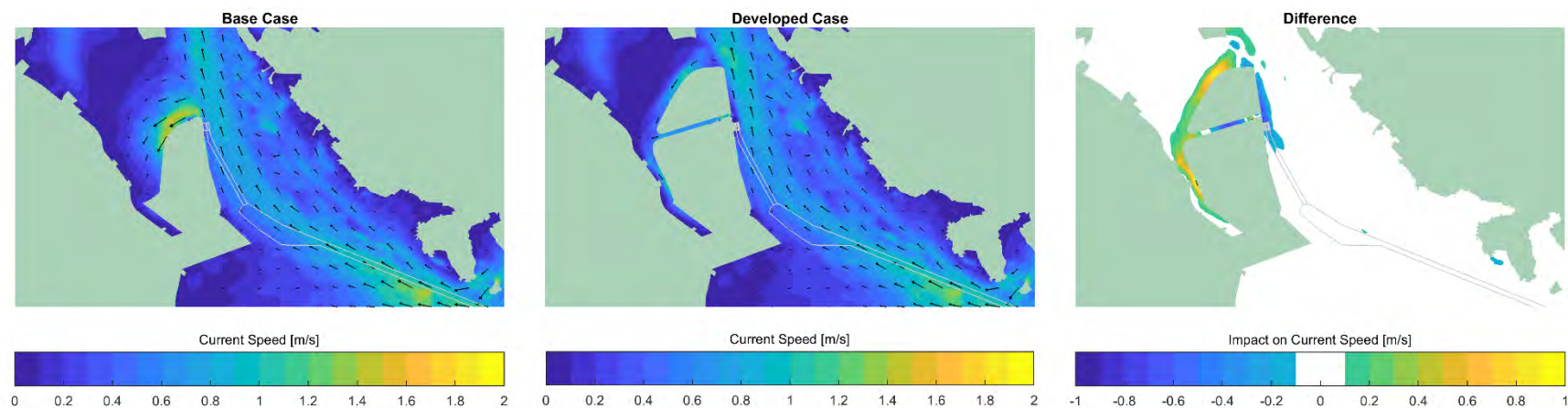


Figure 4-9 Flood Tide Peak Spring Velocity – Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right)

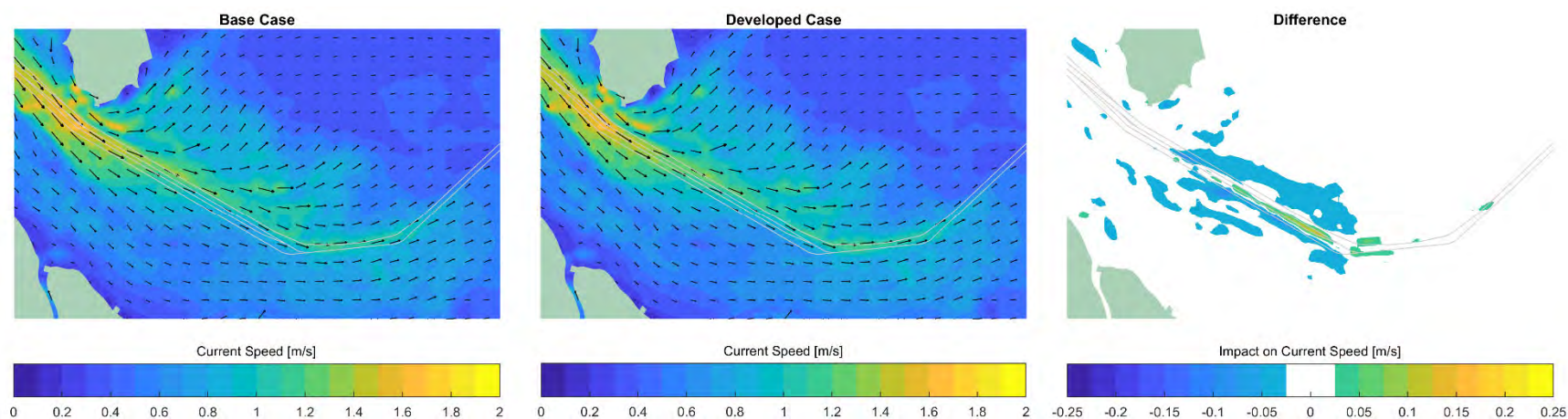


Figure 4-10 Ebb Tide Peak Spring Velocity – Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right)

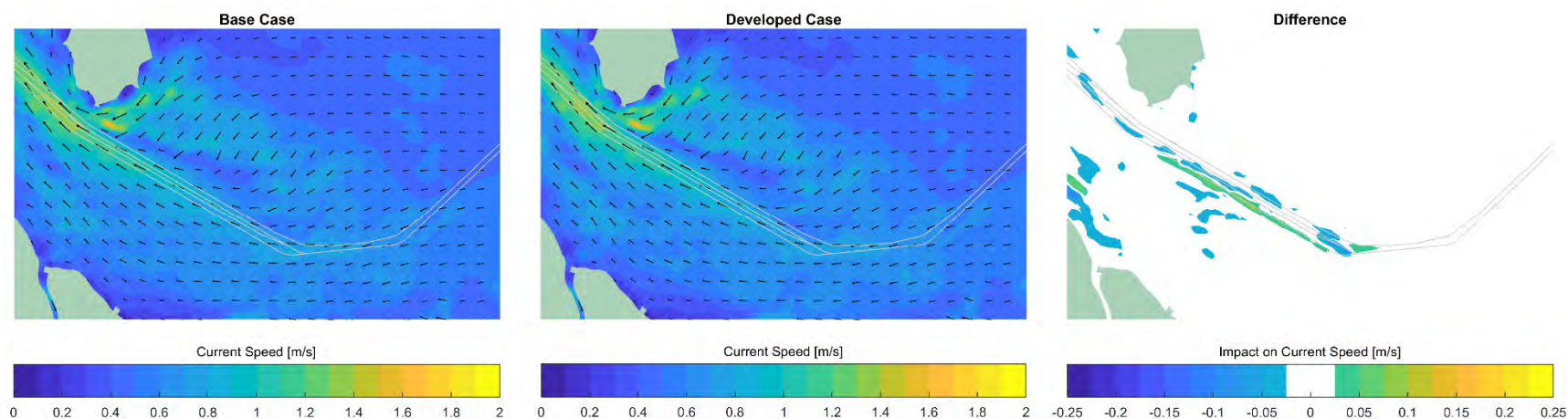


Figure 4-11 Flood Tide Peak Spring Velocity – Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right)

4.4 Wave Climate Impacts

4.4.1 Western Basin Expansion Reclamation Area

Figure 4-12 shows an example of a wave pattern for a strong easterly incident wind condition (9:30am on 30 April 2015) for the Base Case, the Project Channel Geometry Case and the difference between them (with a relatively high tide level). This example was chosen because it represents one of the more significant wave events during the impact assessment period. The main difference caused by the construction of the reclamation is a reduction in wave heights along the shoreline adjacent to the reclamation (during high tide periods when the area is inundated).

A comparison of modelled wave roses for the Base Case and the Project Channel Geometry Case at a location adjacent to the BUF (location shown in Figure 4-12) is provided in Figure 4-14. The difference in modelled wave climate is negligible.

4.4.2 Duplicated Channel

Figure 4-13 shows the wave pattern for the same event (9:30am on 30 April 2015) in the vicinity of the duplicated channel for the Base Case, the Project Channel Geometry Case and the difference between them. It is apparent that the construction of the duplicate channel causes some additional wave reflection for waves from the dominant incident direction (east). The model indicates a very slight reduction in wave height to the south-west of the duplicated channel, and a corresponding slight increase in wave height within the new channel. The nature of these impacts will vary according to wave direction and wave period, however they are likely to be similar (or smaller) in magnitude and extent for other incident wave conditions.

The wave climate impacts at two locations (shown in Figure 4-13) were assessed by analysing the full 12-months of wave model results. Figure 4-15 shows the wave roses for the Base Case and the Project Channel Geometry Case at site ADCP 4. The difference between them is negligible, indicating that there will be no change in wave climate at this location and therefore no consequential change in wave-driven sediment transport on the adjacent coastline.

Figure 4-16 shows the wave roses for the Base Case and the Project Channel Geometry Case at site CD 3. The difference between them is negligible, indicating that there will be no change in wave climate at this location and therefore no consequential change in wave-driven sediment transport on the adjacent coastline.

A comparison of modelled wave roses for the Base Case and the Project Channel Geometry Case at the remaining ADCP sites (1, 2, 3, 5 and 6) are provided in Appendix G. The difference in modelled wave climate at each of these sites is negligible.

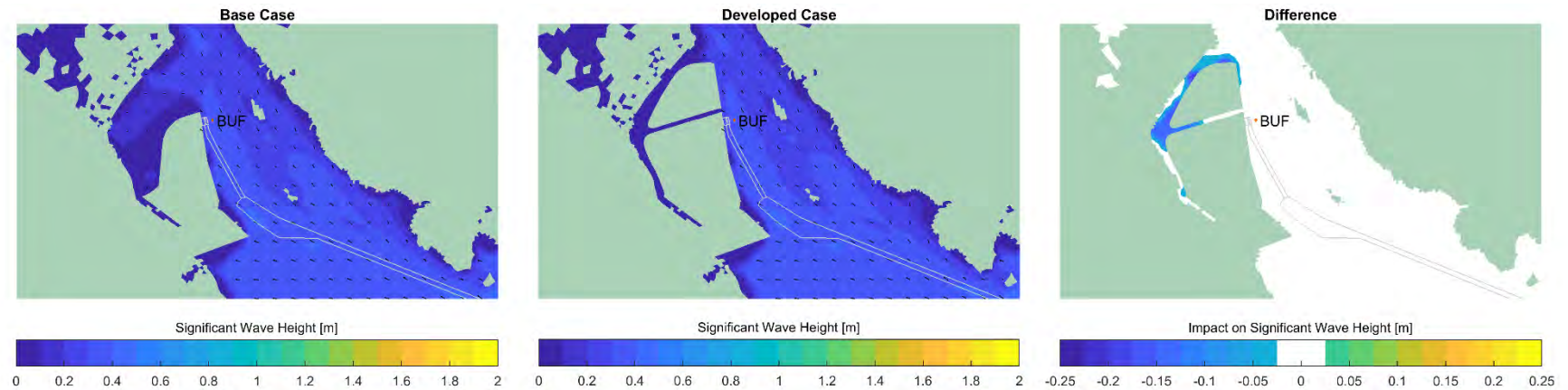


Figure 4-12 Typical Spatial Wave Height and Direction Distribution for the Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right) at High Tide

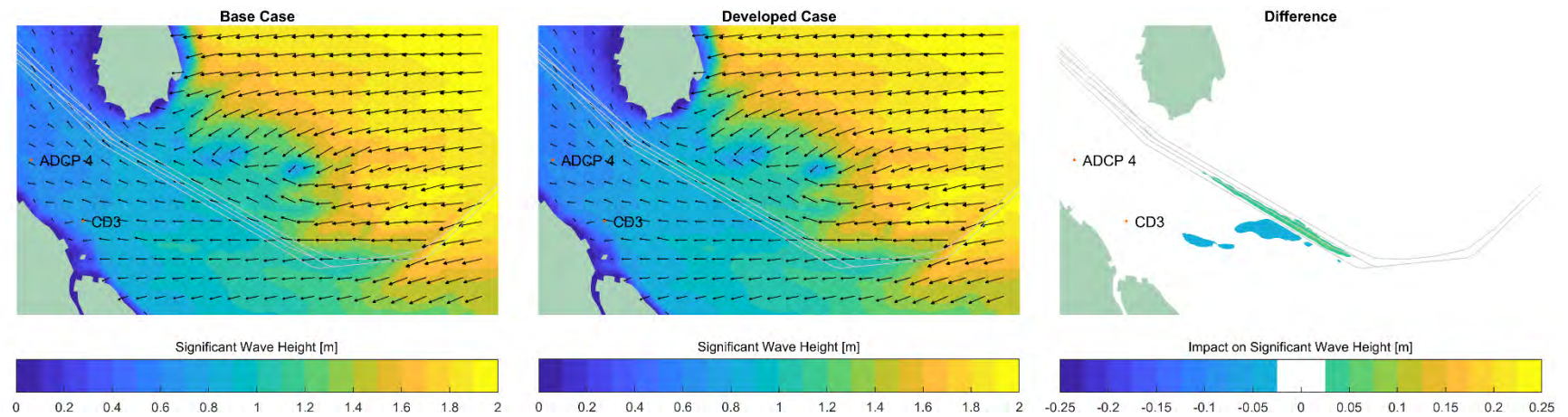


Figure 4-13 Typical Spatial Wave Height and Direction Distribution for the Base Case (Left), Project Channel Geometry Case (Middle) and Difference (Right)

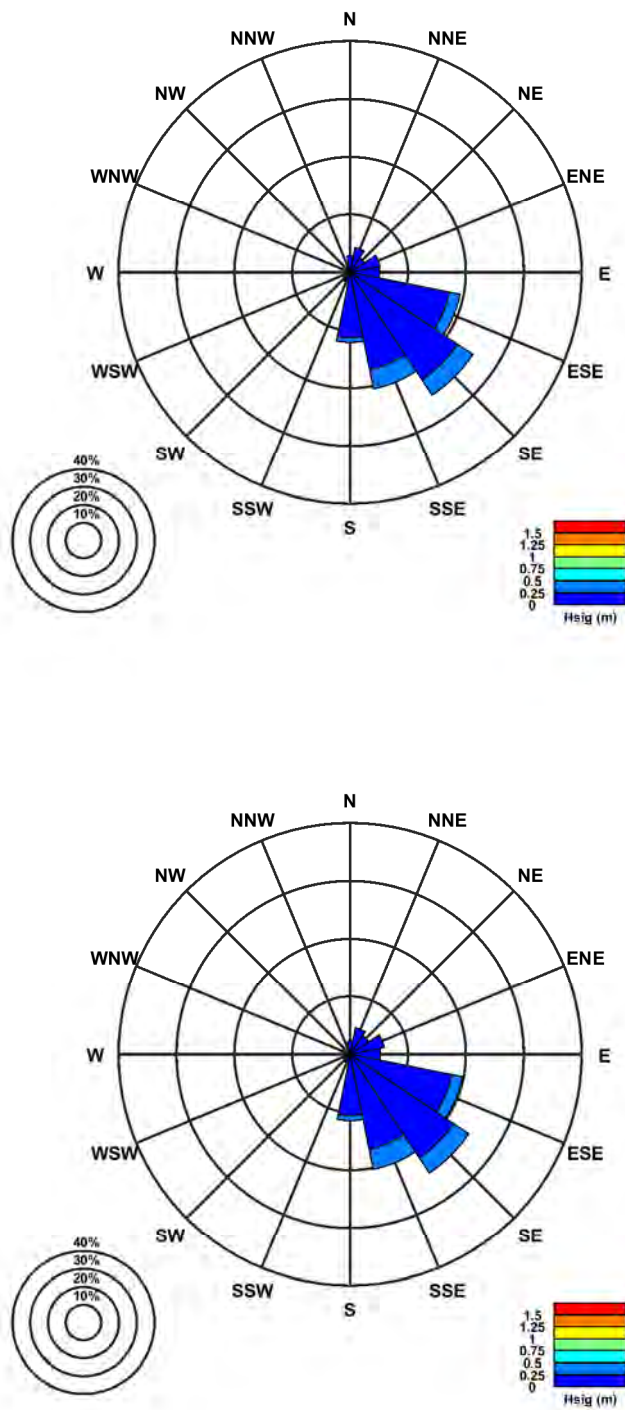


Figure 4-14 Wave Rose at the BUF for the Base Case (Top) and Project Channel Geometry Case (Bottom)

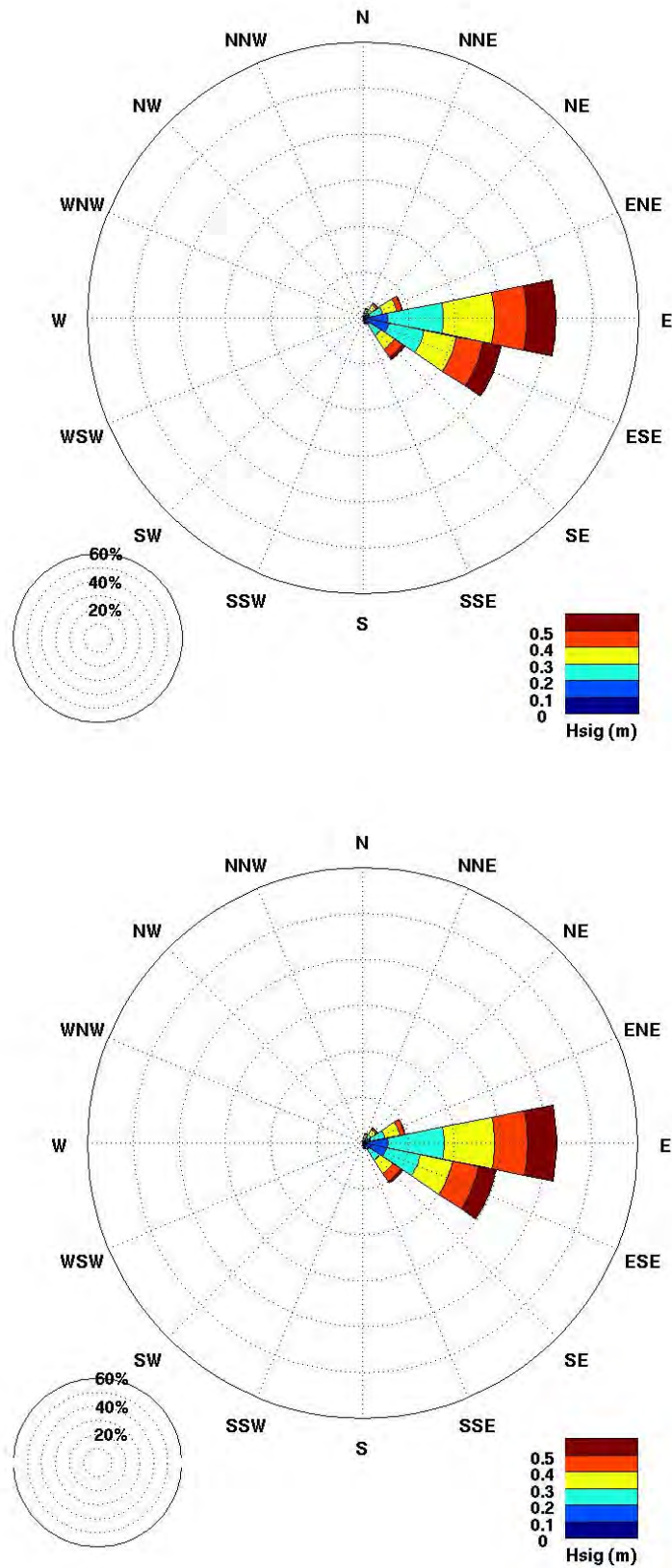


Figure 4-15 Wave Rose at Site ADCP 4 for the Base Case (Top) and Project Channel Geometry Case (Bottom)

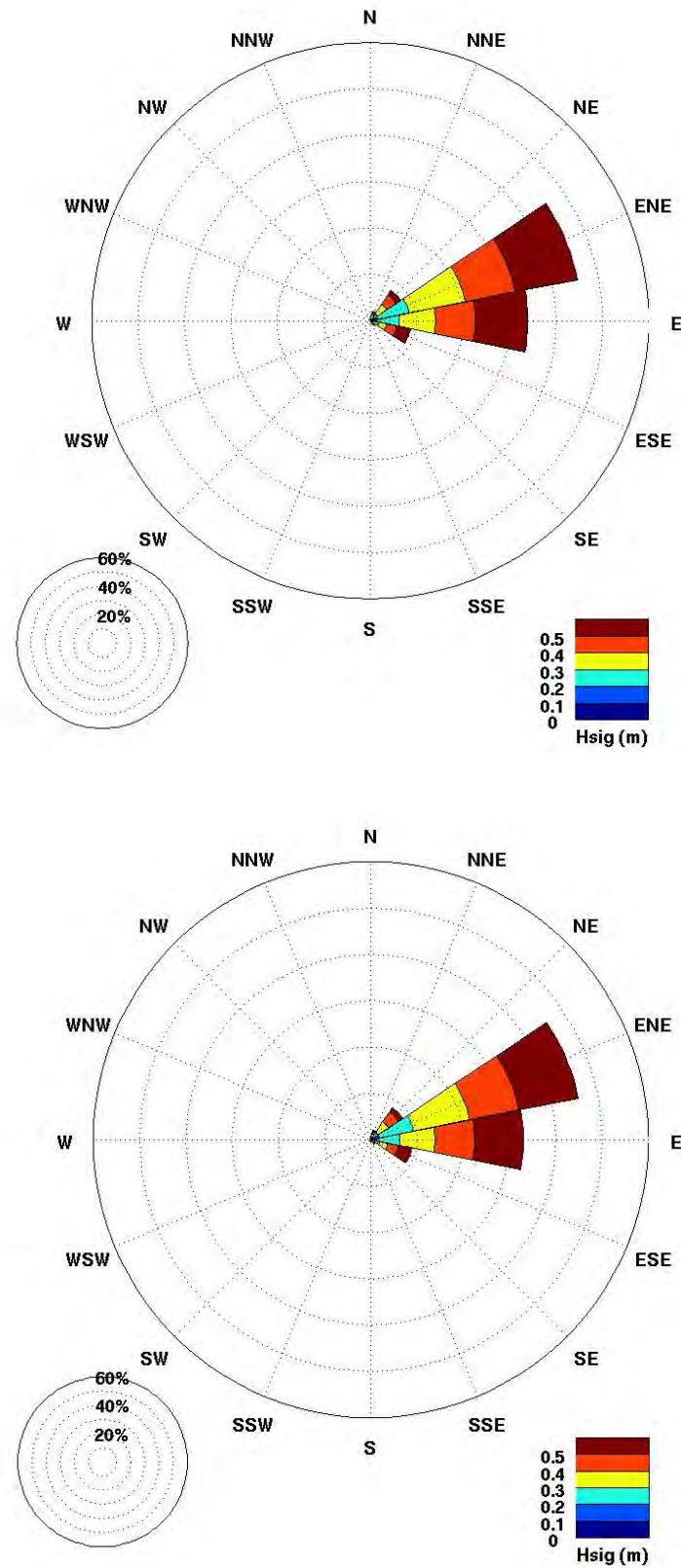


Figure 4-16 Wave Rose at Site CD3 for the Base Case (Top) and Project Channel Geometry Case (Bottom)

4.5 Siltation Impact Assessment

The calibrated TUFLOW FV model was used to investigate the sediment dynamics of the Port for each of the assessment scenarios. The cohesive sediment transport module was used to simulate the ambient turbidity in the water column for the full 12-month assessment period. Sediment exchange with the seabed was modelled (deposition and resuspension) and included the influence of both wave and current generated bed shear stresses.

4.5.1 Western Basin Expansion Reclamation Area

Figure 4-19 illustrates the modelled change to the annual siltation/erosion rate for the Base Case and the Project Channel Geometry Case (i.e. the expected change in the siltation/erosion rate due to construction of the reclamation). The model indicates the potential for some erosion in the channels surrounding the new reclamation areas. This erosion would continue (provided the bed material is erodible) until the channel reaches a new equilibrium depth. Note that this means that the predicted rates of erosion in the channels would not be sustained long term, since the bed morphology would adjust to the new regime and net erosion and accretion will trend towards zero as a new equilibrium profile is obtained.

Stable tidal channels, unless otherwise geologically restricted or subject to strong external influences such as input of sediments by other processes, have been shown to exhibit a well-defined relationship between the volume of tidal flow (tidal prism) and the cross-section area of the flow; a consequence of the fact that they tend to adjust their geometry until a certain equilibrium is achieved. A great many river entrance channels have been studied throughout the world and a number of stability expressions have been developed. The best known of these is that of O'Brien (1969), which is commonly adopted as follows:

$$A = 0.91 \times 10^{-3} P^{0.85}$$

Where A is the river mouth cross-section area below mid-tide level and P is the tidal prism volume between Mean High High Water and Mean Low Low Water (approximately Mean Spring Tide range).

Similar types of regime equilibrium expressions have been found to apply along the tidal reaches of estuaries, upstream of the mouth. Using numerical models of various tidal streams in Eastern Australia, BMT has developed a clear equilibrium relationship that applies to a wide range of channel sizes from minor creeks to large rivers. This relationship is given as:

$$A = 3.1 \times 10^{-3} P^{0.81}$$

The TUFLOW FV model results were used to determine the likely regime status of the completed channels adjacent to the new reclamation areas, with a view to assessing the stability of the channel cross-sections and their likely morphological development. The calibrated TUFLOW FV model was used to estimate the tidal prism for a Mean Spring Tide range (3.2m) at seven transects, shown in Figure 4-17. The cross-section area below mean sea level was calculated using the Digital Elevation Model that was developed for the Port of Gladstone model.



Figure 4-17 Transects Analysed for Likely Morphological Evolution

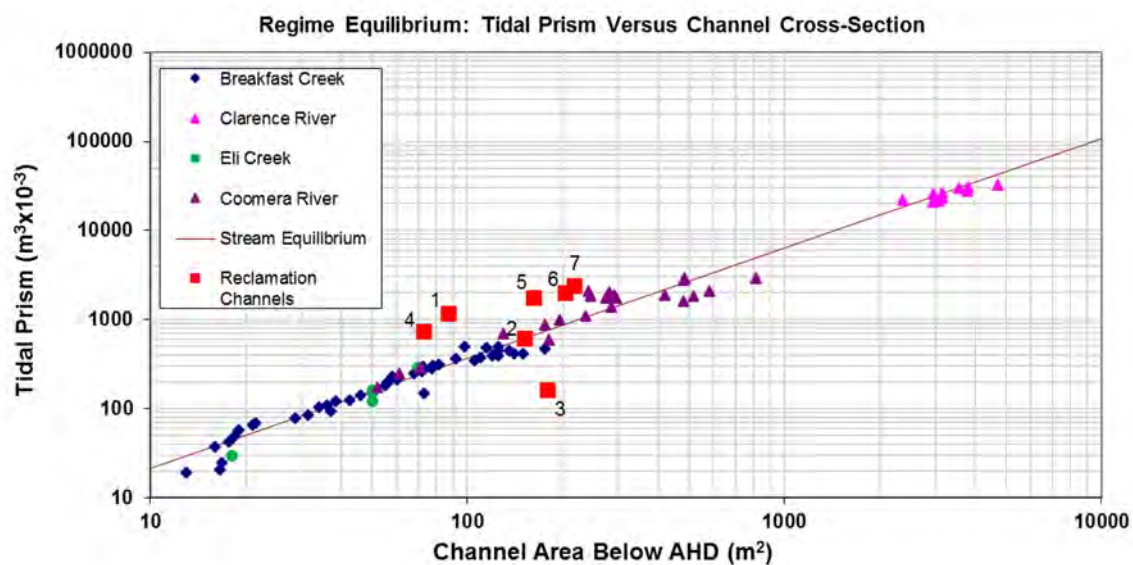


Figure 4-18 Regime Equilibrium: Tidal Channels Adjacent to Proposed WBE Reclamation Areas

The results of the channel stability analysis are presented in Figure 4-18. The channel to the north west of the proposed northern reclamation area is likely to become shallower (accrete) near transect 3, likely to be stable (neither erode nor accrete) near transect 2 and may show a tendency to deepen (erode) near transect 1. The channel to the west of the proposed southern area (the extension to the existing WB reclamation) is likely to deepen (erode) near transect 4, as is the channel between the two WBE reclamation area sections (transects 5, 6 and 7).

The likely equilibrium cross-sectional areas at each of the transects is provided in Table 4-1. It is not possible to use the empirical stream equilibrium relationship to determine whether the channel area will increase or decrease by widening or deepening, except where hard structures are expected to restrict the ability of the channel to widen. In Table 4-2, the potential mean equilibrium depth is provided based on the assumption that the width of the channel at each transect is held constant.

Table 4-1 Likely Equilibrium Cross-Section Areas at Each Transect

Transect	Design Area (m ²)	Tidal Prism (x10 ³ m ³)	Equilibrium Area (m ²)
1	87	1149	251
2	152	605	150
3	179	162	51
4	73	724	173
5	162	1732	350
6	204	1978	390
7	218	2391	455

Table 4-2 Potential Equilibrium Depth at Each Transect

Transect	Design Width (m)	Mean Initial Design Depth (m)	Mean Equilibrium Depth (m)
1	183	0.5	1.4
2	196	0.8	0.8
3	270	0.7	0.2
4	150	0.5	1.2
5	100	1.6	3.5
6	100	2.0	3.9
7	100	2.2	4.5

This assessment will be undertaken again during the detailed design phase of the WBE reclamation area, and the design will be optimised to minimise potential erosion. The detailed design of the toe of the bund wall will consider the potential for erosion of the adjacent channel.

A monitoring program will be implemented to manage any observed impacts in the channels and along the shoreline adjacent to the new reclamation area, including changes to:

- Land forms, including coastal and dune vegetation;
- Existing navigable channels;

- Intertidal areas, including feeding area for migratory birds;
- Wetlands, including groundwater regimes; and
- Existing approved tidal works structures.

Figure 4-19 also indicates that the siltation rate can be expected to increase to the east of the reclamation area, including part of the dredged channel in the vicinity of Fisherman's Landing (though not in dredged areas adjacent to the LNG facilities on Curtis Island). The model results indicate that an increase in maintenance dredging volume in the Fisherman's Landing area of approximately 11% could be expected.

4.5.2 Duplicated Channel

Figure 4-20 illustrates the modelled annual siltation/erosion rate for the Base Case and the Project Channel Geometry Case, and the difference between them (i.e. the expected change in the siltation/erosion rate due to change in bathymetry associated with the new channel). The model results indicate an increase in siltation in the Golding Cutting section of the deeper channel, due to a reduction in velocity caused by the increased water depth.

Analysis of the modelling results indicates that the overall net annualised siltation rate within the shipping channels of the Port is likely to increase by approximately 7% in total following the duplication of the Gatcombe and Golding Cutting Channels. This increase is associated with additional dredging required in the new duplicated section of channel. It will not require a significant change to the maintenance dredging regime, only a proportional increase in the average duration of the typical annual dredging campaign.

The model indicates that the Project will have a negligible effect on siltation rates elsewhere in the Port, including the at small boat harbour at the southern end of Facing Island. Notwithstanding this, the Project proponent is committed to monitor sedimentation in the Facing Island harbour before, during and after the Project and implement mitigation measures to address any significant increase in sedimentation resulting from the Project.

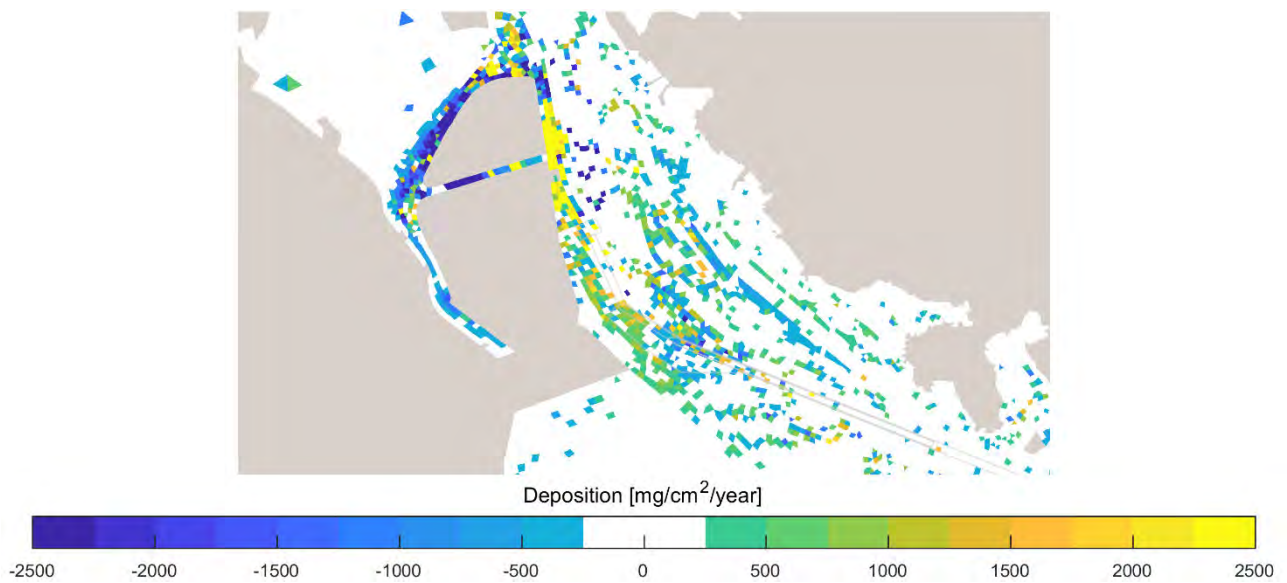


Figure 4-19 Impact to Siltation Rate near the Western Basin Expansion Reclamation Area due to the Project

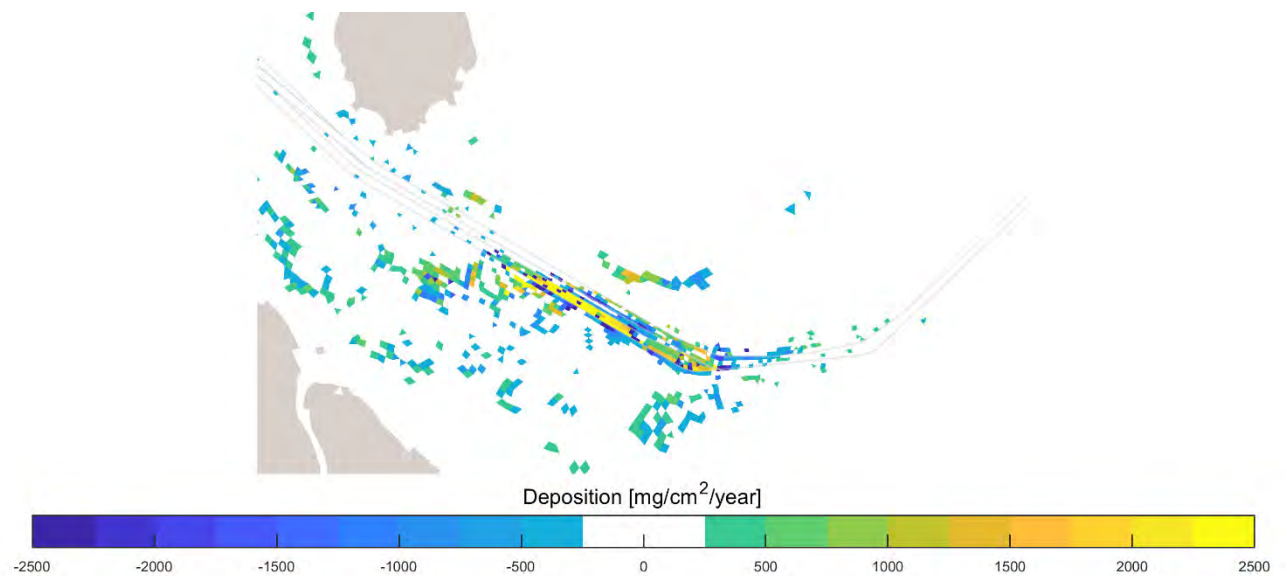


Figure 4-20 Impact to Siltation Rate due to the Project at the Gatcombe and Golding Cutting Channels

4.6 Tropical Cyclone Impact Assessment

4.6.1 Scenario Assessed

A simulation of a tropical cyclone event was undertaken to determine the potential for changes in sedimentation patterns following completion of the Project. For this purpose, the historical cyclone record was assessed and cyclone 'Emily' (April 1972) was chosen for simulation purposes because it had significant magnitude and tracked very close to the Port.

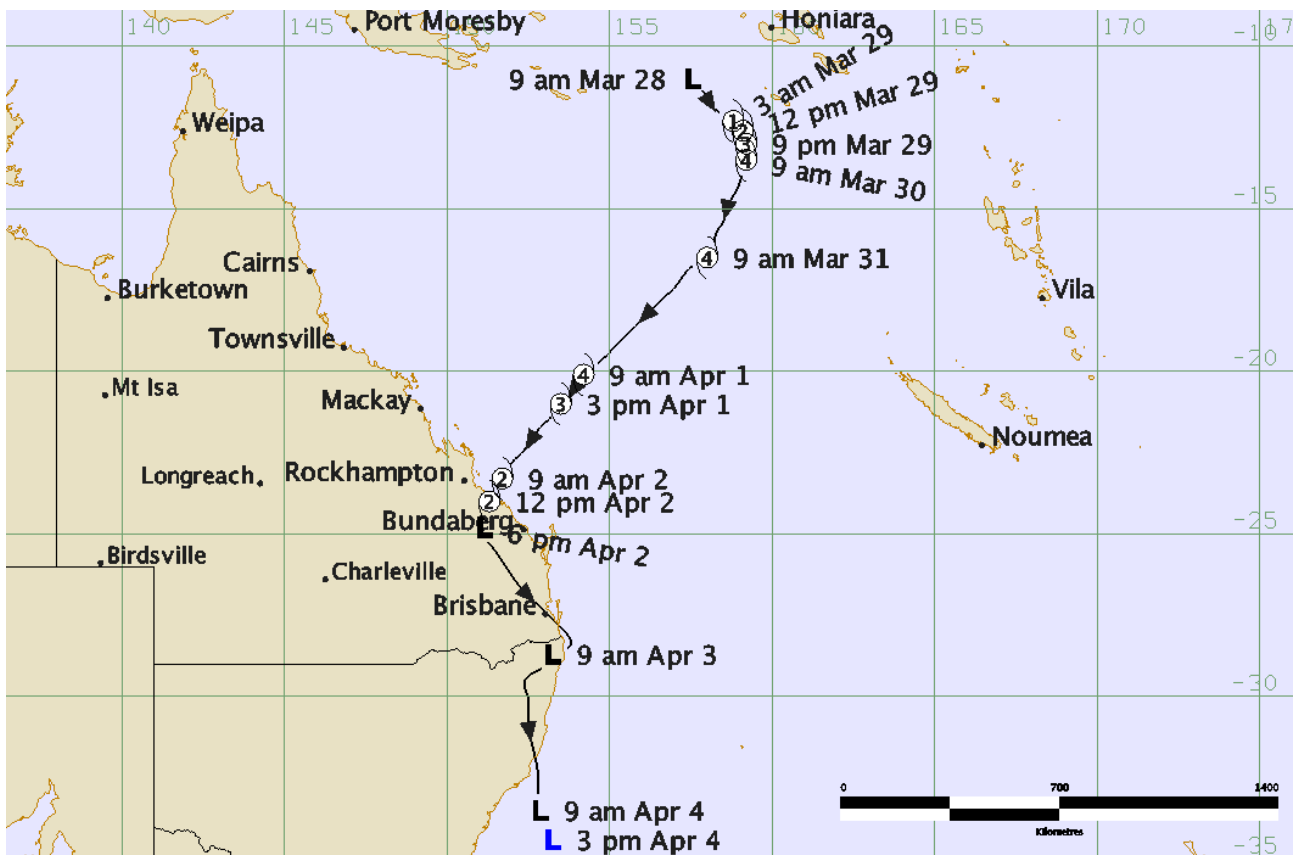


Figure 4-21 Track of Cyclone Emily (from BoM
<http://www.bom.gov.au/cyclone/history/emily.shtml>)

A composite wind field was developed by a superposition (taking the largest value) of the NCEP CFSR modelled wind field (NOAA, 2012) and a Holland parametric cyclonic wind field (Holland, 1980) based on the published BoM cyclone parameters (available at <http://www.bom.gov.au/cyclone/history/>). The combined model was calibrated by comparing the modelled wind speed and direction to the measured wind speed and direction at the Gladstone Radar station. Figure 4-22 shows the result of the calibration process.

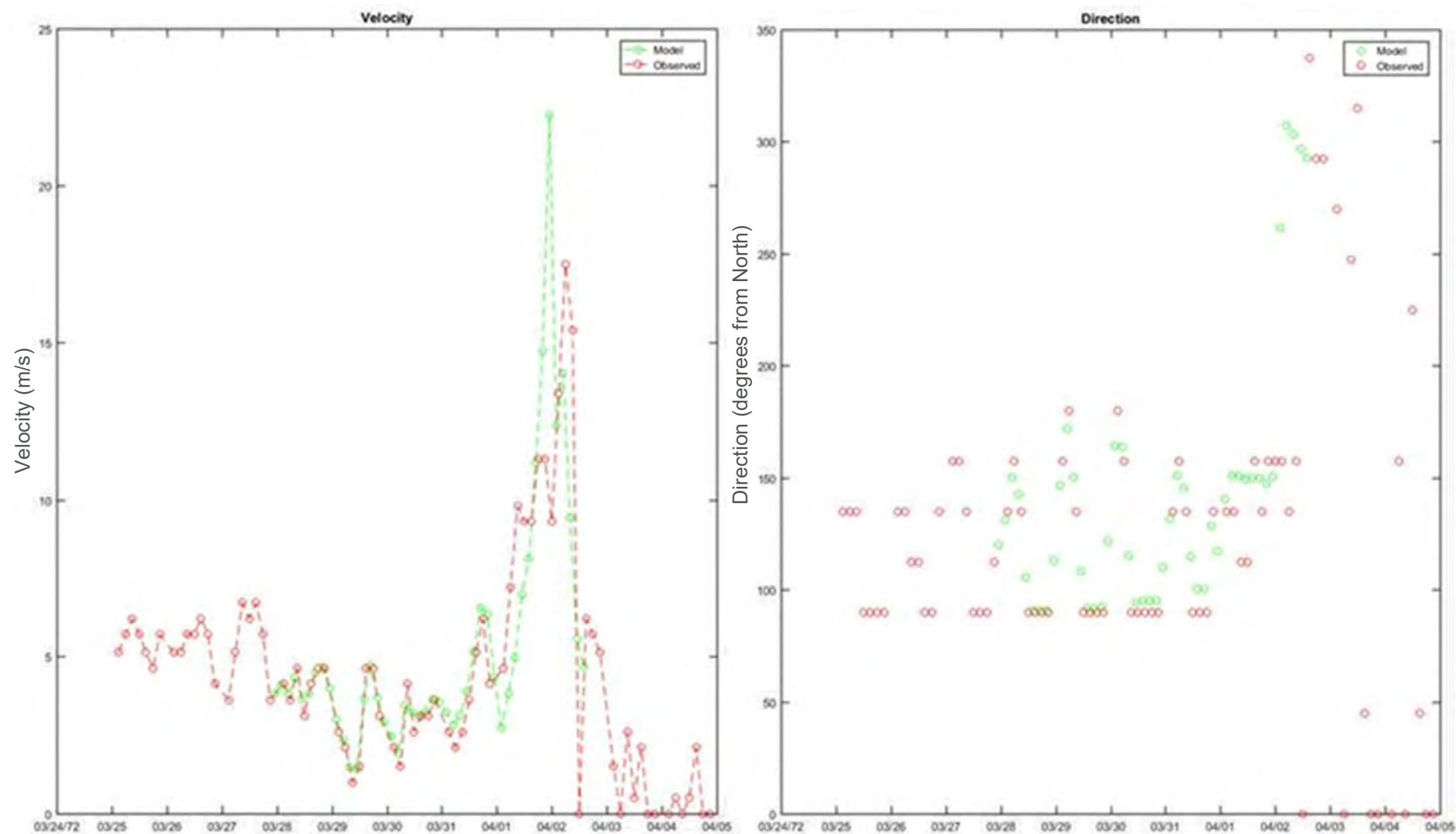


Figure 4-22 Calibration of the Modelled Cyclone Wind Field (Velocity in m/s, Left, and Direction in Degrees from North, right)

4.6.2 Sedimentation Impacts

A time series of the net sedimentation for the Base Case simulation (existing channel geometry) and for the Developed Case simulation (duplicated channel geometry) within the channel area is provided in Figure 4-23. The model results indicate that an overall increase in siltation of approximately 4% could be expected for this cyclone scenario following duplication of the shipping channels.

Maps of the spatial distribution of net sedimentation for the Base Case simulation and for the Developed Case simulation are shown in the top two panels of Figure 4-24. The bottom panel of Figure 4-24 shows the difference (Developed minus Base Case). The model results indicate some increase in net sedimentation in the Developed Case in the duplicated Golding Cutting Channel.

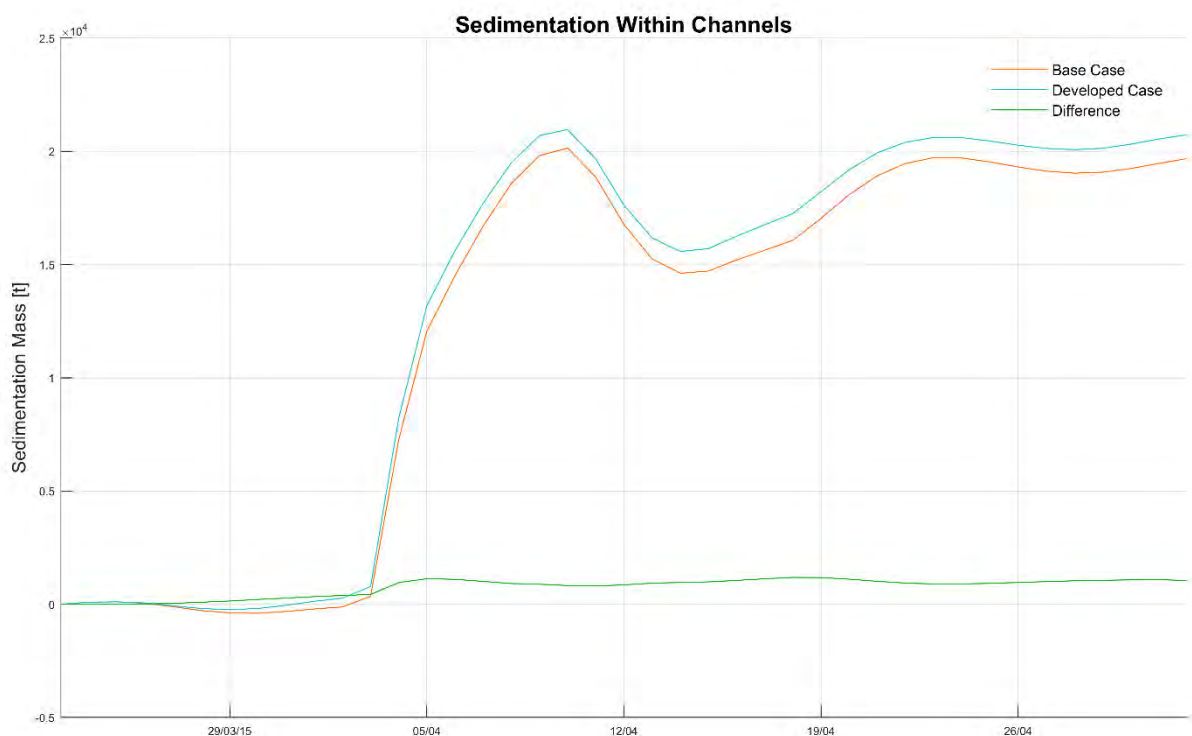


Figure 4-23 Time Series of Deposition within Channels – Cyclone Simulation

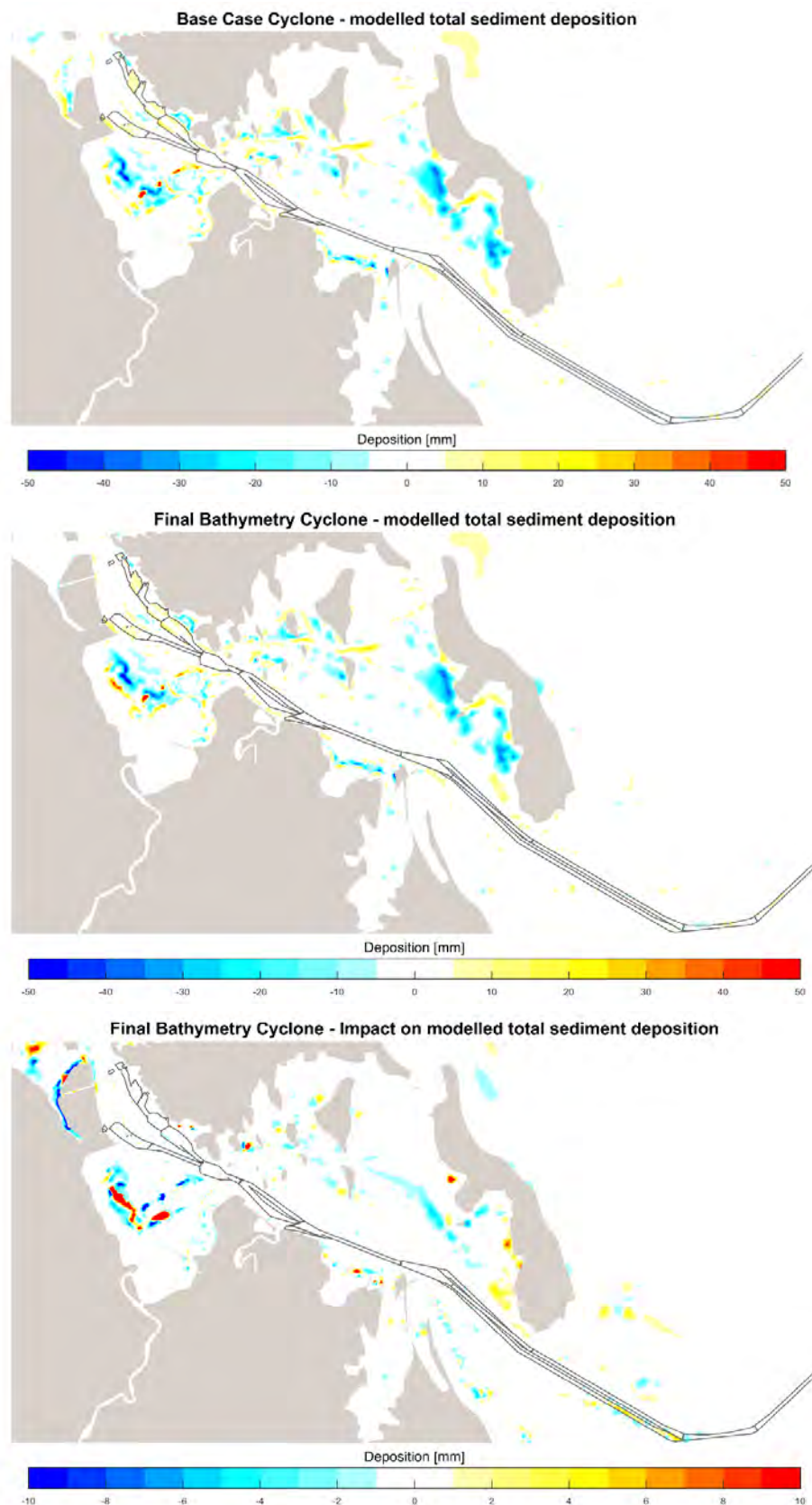


Figure 4-24 Net Sedimentation During a Cyclone Event – Base Case (Top), Developed Case (Middle) and Difference (Bottom)

4.7 Climate Change Impact Assessment

4.7.1 Intergovernmental Panel on Climate Change (IPCC, 2014)

The global average rate of SLR measured over the last century was 1.7 mm/year (Church et al., 2010). SLR is predicted to continue, in order of decreasing contribution:

- Ocean water expanding gradually as it heats (thermal expansion);
- The melting of glaciers;
- Retreat of the Greenland ice shelf; and
- Antarctic ice losses.

Even if greenhouse gas emissions were stabilised at present-day levels, SLR is expected to continue for hundreds of years due to the effect of thermal expansion alone.

The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC 2014) provides SLR projections for a range of global greenhouse gas emission scenarios. The projections for SLR (and other climate variables reported by the IPCC) rely heavily on the Coupled Model Intercomparison Project, Phase 5 (CMIP5) which is a collaborative climate modelling process coordinated by the World Climate Research Programme.

Figure 4-25 summarises projected increases to global mean surface air temperature and global mean sea level for the four principal emission scenarios, or Representative Concentration Pathways (RCPs). The global SLR projections are also illustrated in Figure 4-25. The IPCC give the following descriptions to the RCPs:

- RCP2.6: global greenhouse gas emissions peak between 2010 and 2020 and substantially decline thereafter.
- RCP4.5: global greenhouse gas emissions peak around 2040 and decline thereafter.
- RCP6.0: global greenhouse gas emissions peak around 2080 and decline thereafter.
- RCP8.5: global greenhouse gas emissions continue to rise throughout the 21st century.

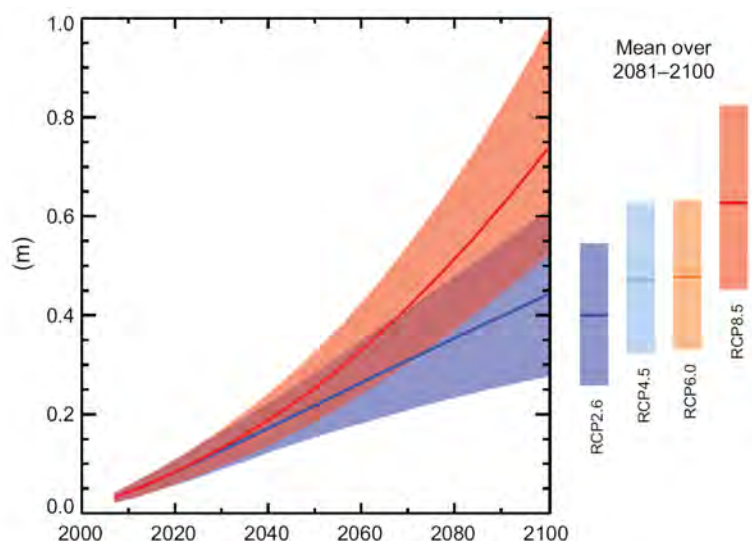


Figure 4-25 Projections of Global SLR Relative to 1986-2005 Mean Sea Level (IPCC 2014)

4.7.2 Ocean Hazards Assessment – Stage 3 (James Cook University, 2004)

This study provided storm surge plus tide statistics for 50 locations along the east coast of Queensland and was commissioned by the former Queensland Environmental Protection Agency with support from the BoM and the Greenhouse Special Treasury Initiative. The study report is available via the Queensland Government Long Paddock website:

<https://data.longpaddock.qld.gov.au/static/publications/vulnerability-to-cyclones/stage3.pdf>

The study produced storm surge plus tide return period curves between 10 and 1000 years. The assessments also included 'Greenhouse Scenarios' with the following key assumptions:

- Combined effect of an increase in tropical cyclone MPI of 10% and a poleward shift in tracks of 1.3°.
- Increase in frequency of tropical cyclones of 10%.
- Mean SLR of 0.3 m by 2050.

The SLR allowance was based on recommendations in the now superseded IPCC third assessment report. The modelled sea level rise predictions from the most recent IPCC report presented in AEIS Chapter 11 (climate and climate change assessment) are consistent with this SLR value over a 50-year planning period. The mean SLR component has an almost linear effect on the resultant storm tide levels while the 10% increase in cyclone frequency/intensity has negligible impact. The combined increase in intensity and poleward shift in tracks becomes increasingly significant with large return periods. The storm tide levels predicted with the combined climate change scenarios are presented in Table 3-3.

Table 4-3 Peak Storm Tide Levels (Combined Climate Change Scenarios 50 Year Planning Period – 0.3m Sea Level Rise)

Location	Storm Tide Level (m LAT)		
	100 year ARI	500 year ARI	100 year ARI
Gladstone	5.60	6.45	6.78

Source: Queensland Government (James Cook University, 2004)

4.7.3 Queensland Government Coastal Hazard Mapping

Under the Queensland State Planning Policy, 'coastal hazards' refer to:

- (1) Temporary and permanent loss of land due to shoreline erosion.
- (2) Permanent inundation due to SLR.
- (3) Temporary inundation due to storm tide.

Plans showing the indicative extent of each hazard for the entire State have been produced by the former Department of Environment and Heritage Protection (EHP). The state coastal hazard area plans are of a regional scale. Detailed assessments that meet or exceed the minimum standards described in the [Coastal Hazard Technical Guide](#) (EHP, 2013) can be used to support amendments to the plans. An index of the coastal hazard mapping is available at <https://environment.ehp.qld.gov.au/coastal-hazards/>.

The Coastal Hazard Technical Guide adopted a planning period of 100 years for the assessment of erosion due to SLR. A SLR of 0.8m by the year 2100 was adopted based on IPCC projections.

4.7.4 Project Climate Change Impact Assessment

The modelling results presented in Section 4.3 indicate that the deepening of shipping channels will have no impact on existing water levels in the Port. The wave climate on coastlines adjacent to the duplicated channels will not be impacted (Section 4.4). The deepening of the shipping channels is therefore not likely to cause any change to the projected impacts of climate change and SLR in the Project area. Since SLR will have the effect of raising the level of LAT, and the design level of the channels is relative to LAT, the depth of the channels relative to the mean sea level is not expected to change over time.

Detailed design of the WBE reclamation area will need to consider the potential influence of climate change on design levels, and include allowances for wave setup and wave runup.

5 Modelling of Dredging Activities

5.1 Dredging Program

5.1.1 Initial Dredging Works

Initial dredging is required to establish an access channel and BUF at the northeast corner of the existing WB reclamation area. The dredging will be carried out by both cutter suction dredger (CSD) and trailing suction hopper dredger (TSHD). The alignment of the channel and area to be dredged are shown in Figure 5-1, and the dredging volumes and methodology details are summarised in Table 5-1 (all material to be pumped into the WB and WBE reclamation areas). The BUF is to be completed before the initial dredging and channel duplication dredging works commence.

Table 5-1 Initial Dredging Works Requirements

Dredging Parcel	Design Depth (m LAT)	Volume (m ³)	Methodology
Access channel in the immediate vicinity of the barge unloading facility	-7.0	100,000	CSD
Access channel	-7.0	150,000	TSHD

5.1.2 Stage 1 Dredging

Stage 1 dredging is the first of the two main stages for the Channel Duplication dredging program. This stage involves the removal of 7.25×10^6 m³ of material from the deepening of the Gatcombe and Golding Cutting bypass channels to achieve a design bed level of -13.5 m LAT. Methodology for this phase of dredging will involve a TSHD working almost exclusively in the Golding Cutting Channel area (i.e. 7.20×10^6 m³) with only a small volume of material removed from the Gatcombe Channel area (i.e. 50,000 m³). The TSHD pumps the dredged material into barges, which are unloaded by backhoes at the BUF and transferred into the WB and WBE reclamation areas. The extent of the area to be dredged is presented in Figure 5-2.

5.1.3 Stage 2 Dredging

Stage 2 dredging involves further removal of material (5.35×10^6 m³) to achieve the channel design depth of -16.1m LAT. The dredging methodology for this stage is the same as the Stage 1 dredging and the final dredged material location is the WB and WBE reclamation areas. The dredged material volume to be removed from the Gatcombe Channel is larger than the Stage 1 dredging (i.e. 0.45×10^6 m³), however the majority of the dredged material for Stage 2 will be removed from the Golding Cutting Channel area (i.e. 4.9×10^6 m³). The area to be dredged for this stage is presented in Figure 5-3. Stage 2 may be undertaken immediately after Stage 1, so the modelling assumes that this is the case.

5.1.4 Dewatering Material Within Reclamation Areas

While dredging activities are taking place, dewatering of the material placed in the reclamation occurs and tailwater will be discharged in accordance with licenced water quality limits.



Figure 5-1 Barge Access Channel and Barge Unloading Facility

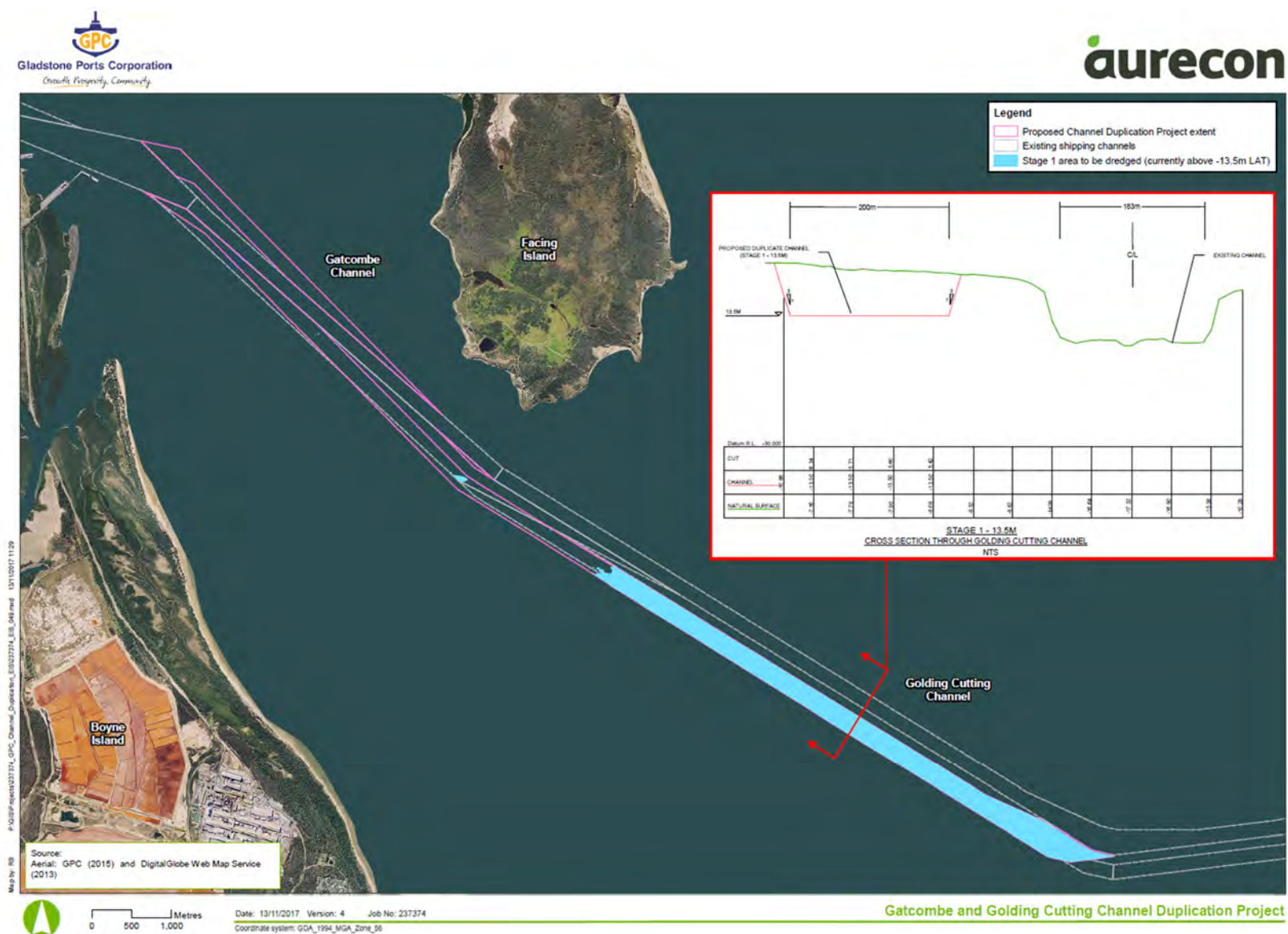


Figure 5-2 Channel Duplication Capital Works Extent - Stage 1



5.2 Model Parameterisation

The methodology used to estimate the likely generation and advection/dispersion of suspended sediment plumes is consistent with that used in previous reports on dredging within the Port of Gladstone (BMT WBM, 2017a). Suspended sediment plumes are produced during the dredging operation by a number of processes, all of which are represented in the numerical model. Source terms for each of these processes were developed in consultation with an expert dredging consultant and based on results from previous monitoring of similar dredging activity. The source term for each process varied according to the production rate and the proposed dredging hours per week for each type of dredging operation. Descriptions of the likely dredging operations alongside the key assumptions used in the dredge modelling are presented in the following sections.

5.2.1 Initial Dredging Works

The material to be dredged was assessed by analysing available particles size distribution data from boreholes in the vicinity of the dredging work. An overall bulk average of 55% fines (silts and clays) was adopted for this stage of the dredging activity. It was further assumed that the fines are composed of 67% clay particles and 33% silt particles. The major plume sources are:

CSD:

The dredging of the channel in the vicinity of the BUF will be undertaken by a CSD. The expected duration of the CSD dredging activity is approximately 4 weeks.

The dredging assumptions are:

- Small CSD;
- Quantity to be dredged: 100,000 m³;
- Productivity: 250 m³/hour;
- Dredging hours / week: 100;
- Weekly production: 25,000 m³ / week; and
- Source rate estimated to be released as a suspended sediment plume:
 - 3% of the fines in the materials to be dredged:
$$0.03 \times 250 \text{ m}^3/\text{hour} \times 2.05 \text{ tonnes/m}^3 \times 1,000 \text{ kg/tonne} / 3600 \text{ seconds/hour} \times 0.55 = 2.35 \text{ kg/s}$$

(1.6 kg/s of clay particles + 0.75 kg/s of silt particles).

TSHD:

It is proposed to use a dredger with a similar capacity to the TSHD Brisbane (3,000 m³) to complete the dredging of the access channel to the barge unloading facility. During overflow, 80% of the available fines in the material being dredged are lost to the overflow, which means the efficiency of dredging is $1 - 0.8 \times 0.55 = 56\%$ (it is conservatively assumed that the fines return to the dredging footprint and must be re-dredged). It is assumed that 15% of the fines in the overflow go into the

suspended sediment plume. The expected duration of the TSHD dredging activity is approximately 2.5 weeks.

The dredging assumptions are:

- 3,000 m³ TSHD;
- Quantity to be dredged: 150,000 m³;
- Dredging time: 35 min per load (including 25 min non-overflow + 10 min overflow). Normal cycle time: 2 hours;
- Average load: 900 m³ (insitu) – small load due to limited draft;
- Effective production rate (non-overflow): 1,765 m³ / hour;
- Effective production rate (overflow): 988 m³ / hour;
- Dredge operational hours (normal total cycle) / week: 133. Additional down time: ~0.5 hours / cycle;
- Weekly Production: ~60,000 m³ / week; and
- Source rate estimated to be released as a suspended sediment plume:
 - Drag head and propeller wash: 4% of the fines in the materials to be dredged.

$0.04 \times 1,765 \text{ m}^3/\text{hour} \times 2.05 \text{ tonnes} / \text{m}^3 \times 1,000 \text{ kg/tonne} / 3,600 \text{ seconds/hour} \times 0.55 = 22.1 \text{ kg/s}$
(14.7 kg/s of clay particles, 7.4 kg/s of silt particles).

This source applies for the full 35 minutes of dredging that occurs each cycle.

- Overflow: 80% of the fines in the materials that will go overboard through the overflow and 15% of this volume will go in to the passive plume.

$0.80 \times 0.15 \times 1,765 \text{ m}^3/\text{hour} \times 2.05 \text{ tonnes} / \text{m}^3 \times 1,000 \text{ kg/tonne} / 3,600 \text{ seconds/hour} \times 0.55 = 66.3 \text{ kg/s}$

(44.2 kg/s of clay particles + 22.1 kg/s of silt particles).

This source applies for the 10 minutes of overflow dredging that occurs each cycle.

Tailwater Discharge:

- Water is assumed to be discharged from the reclamation at a flow rate of 2.8 m³/s with a concentration of 100 mg/L of clay particles. This concentration is derived from the maximum permitted suspended sediment concentration limit during previous campaigns within the Port of Gladstone. Discharge from the licenced discharge point will only occur when the water quality complies with the licenced water quality limits. Discharge from the two existing WBRA discharge points will not occur at the same time as at the proposed WBE reclamation area discharge point. The proposed discharge location is shown in Figure 5-4.



Figure 5-4 Project Tailwater Discharge Locations

Model configuration:

The BUF is to be completed before the initial dredging and channel duplication dredging works commence (the completed BUF is included in the model). Both the northern and southern WBE reclamation areas are included in the model fully constructed. Bathymetry elsewhere in the Port is assumed to be the same as the existing bathymetry.

5.2.2 Stage 1 Dredging

5.2.2.1 Material Composition

The material to be dredged was classified from borehole data into five material types. These material types, alongside their sediment composition and total volume of material to be dredged, are presented in Table 5-2. For modelling purposes, a sediment composition based on the weighted average of the volume to be dredged was used, since the geotechnical data indicates that sediment types are intermixed. Based on advice received from the expert dredging consultant, 25% of the fines (silt and clay fractions) in the sandy clay material were assumed to be released into suspended sediment plumes (the remainder stay in the hopper in silt/clay lumps). For the silty clay material, 50%

of the in-situ fines (silt and clay fractions) were assumed to be available for release into suspended sediment plumes. Table 5-2 shows the proportion of each material type and its composition, including calculation of the estimated total volume that is released as clay and silt particles in suspension.

Table 5-2 Channel Duplication Material Classification and Composition – Stage 1

Sediment Class	Sand	Gravelly Sand	Sandy Gravel	Sandy Clay	Silty Clay	
Total Volume m ³	1,526,000	761,000	348,000	3,658,000	638,000	
Percent of fines going into suspension	100%	100%	100%	25%	50%	
Clay	0%	0%	4%	13%	30%	
Silt	16%	19%	12%	1%	15%	
Sand/Gravel	84%	81%	84%	45%	10%	
Clay Balls	0%	0%	0%	41%	45%	
Percentage of Total Volume	22%	11%	5%	53%	9%	Totals:
Clay Particles in Suspension	0%	0%	0%	7%	3%	10%
Silt Particles in Suspension	4%	2%	1%	1%	1%	8%
Sand/Gravel	18%	9%	4%	24%	1%	56%
Clay Balls	0%	0%	0%	22%	4%	26%

Overall, 10% of the material to be dredged is available to be released into plumes as clay particles and 8% as silt particles. In the model, it has been conservatively assumed that an overall percentage of 20% of the material is available to go into suspension, comprising 11% clay particles and 9% silt particles.

During overflow, 80% of the available fines in the material being dredged are lost to the overflow, which means the efficiency of dredging is $1 - 0.8 \times 0.2 = 84\%$. It is assumed that 15% of the fines in the overflow go into the suspended sediment plume.

5.2.2.2 Dredger track Schematisation

In order to represent the activity of the dredger realistically in the model, the area to be dredged in Stage 1 was divided into two areas and the dredger operated in one of the two areas each cycle depending on a tidal state criterion. At the commencement of dredging within each cycle, if the tide state was approaching high tide (tide about to go out) then dredging was modelled to occur on the inner section of channel (from GG 15 to GG 20 in Figure 4-1). If the tide state was approaching low tide (tide about to come in) then dredging was modelled to occur on the outer section of channel (from GG 20 to GG 23 in Figure 4-1).

Each barge cycle takes 12.25 hours, and there are 10 cycles per barge each week. This makes a total of 40 cycles using 4 barges. Spread out evenly over the week, this means that the TSHD loads for 165 minutes and then has 87 minutes changeover time before starting to load the next barge.

The overall duration of Stage 1 dredging is estimated at 33 weeks.

5.2.2.3 Plume Generation Rates

The key assumptions used to derive the dredged material loads for Stage 1 dredging are:

TSHD and Barges:

The effective load of each barge is 5,500 m³ and the TSHD is assumed to operate for 20 minutes prior to commencement of overflow. The effective production rate prior to overflow is therefore $5,500 \times 60 / (0.84 \times 145 + 20) = 2,327 \text{ m}^3/\text{hour}$, and the effective production rate during overflow is $2,327 \times 0.84 = 1,955 \text{ m}^3/\text{hour}$. The pumping rate of material into the barges is 2,327 m³/hour for the whole 165 minutes of dredging each cycle.

- TSHD Draghead/Propwash - 4% of the fines in the materials to be dredged go into a plume.

The release rate of fines due to draghead/propwash is therefore:

$$0.04 \times 2,327 \text{ m}^3/\text{hour} \times 2.05 \text{ tonnes/m}^3 \times 1,000 \text{ kg/tonne} / 3,600 \text{ seconds/hour} \times 0.2 = 10.6 \text{ kg/s}$$

It is assumed that this source is 55% clay particles (5.8 kg/s) + 45% silt particles (4.8 kg/s).

This source applies for the full 165 minutes of dredging that occurs each cycle.

- Barge Overflow.

The release rate of fine material through the overflow is:

$$0.80 \times 0.15 \times 2,327 \text{ m}^3/\text{hour} \times 2.05 \text{ tonnes/m}^3 \times 1,000 \text{ kg/tonne} / 3,600 \text{ sec/hour} \times 0.2 = 31.8 \text{ kg/s}$$

It is assumed that this source is 55% clay particles (17.5 kg/s) + 45% silt particles (14.3 kg/s).

This source applies for the 145 minutes of overflow dredging that occurs each cycle.

Tailwater Discharge:

Tailwater discharge is included in the modelling, with a flow rate of 0.35 m³/s with a concentration of 100mg/L of clay. This concentration is derived from the maximum permitted suspended sediment concentration limit during previous dredging campaigns within the Port of Gladstone. Discharge from the licenced discharge points will only occur when the water quality complies with the licenced water quality limits. The flow rate equates to 30,240 m³/day which is approximately the daily volume of material placed in the reclamation area. Tailwater discharge ceases at the completion of the dredging activity. Discharge from the two existing WBRA discharge points will not occur at the same time as at the proposed WBE reclamation area discharge point.

5.2.3 Stage 2 Dredging

5.2.3.1 Material Composition

The assumed particle size distribution for material to be dredged in the Stage 2 capital works is the same as that of Stage 1, in accordance with advice from the expert dredging consultant.

5.2.3.2 Dredger track Schematisation

In order to represent the activity of the dredger realistically in the model, the area to be dredged in Stage 2 was divided into a total of five areas. Dredging in the Gatcombe Channel was split into two areas, one to the north of the existing Gatcombe Channel and one to the south. Dredging in these areas was undertaken alternating between the two areas, with the cycles dispersed evenly through the entire dredging campaign (approximately 10% of the total Stage 2 dredging cycles). Dredging in the Golding Cutting Channel was split into three areas. At the commencement of dredging within each cycle, if the tide state was approaching high tide (tide about to go out) then dredging was modelled to occur on the inner section of channel (from GG 12 to GG 16 in Figure 4-1). If the tide state was approaching low tide (tide about to come in) then dredging was modelled to occur on the outer section of channel (from GG 20 to GG 23 in Figure 4-1). If the tide state was intermediate (mid-tide) then dredging was modelled to occur in the central section of channel (from GG 16 to GG 20 in Figure 4-1).

Each barge cycle takes 12.25 hours, and there are 10 cycles per barge each week. This makes a total of 40 cycles using 4 barges. Spread out evenly over the week, this means that the TSHD loads for 165 minutes and then has 87 minutes changeover time before starting to load the next barge.

The overall duration of Stage 2 dredging is estimated at 25 weeks.

5.2.3.3 Plume Generation Rates

The key assumptions used to derive the dredged material loads for Stage 2 dredging are the same as those for Stage 1 (the same TSHD and tailwater plume source rates were used).

5.2.4 Model Configuration for Stage 1 and Stage 2 Dredging

Stage 1

- Include both northern and southern parts of the WBE reclamation areas;
- Include the BUF structure and barge access channel (dredged to -7 m LAT); and
- All other bathymetry as per existing.

Stage 2

- Include both northern and southern parts of the WBE reclamation areas;
- Include the BUF structure and barge access channel (dredged to -7 m LAT);
- Include bathymetry of Gatcombe and Golding Cutting Channels as at the end of Stage 1 dredging; and
- All other bathymetry as per existing.

5.2.5 'Worst Case' Dredging Impacts

A 'worst case' assessment of potential impacts to turbidity and deposition rate was derived by calculating the highest modelled change in the turbidity and deposition rate percentiles over all of the

14-day assessment windows throughout the dredging campaigns (all stages). Therefore the 'worst case' represents the potential change to turbidity and deposition rates when the dredging activity and environmental conditions are most adverse during the campaign (high rate of plume release together with high levels of resuspension of dredged sediment).

5.2.6 'Cumulative Case' Dredging Scenarios

Two 'cumulative case' scenarios were investigated to examine the potential cumulative impact that could result from other projects or events taking place during the Channel Duplication capital dredging works. The two scenarios involved a 'typical' Port-wide maintenance dredging campaign (i.e. 260,000m³) and, separately, a flood event with an annual exceedance probability of approximately 1 in 100.

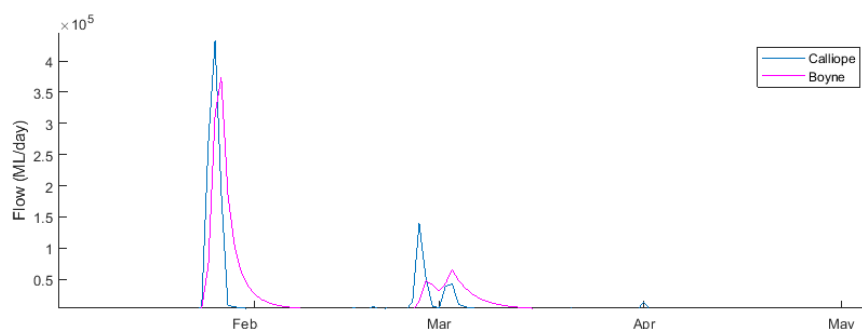
5.2.6.1 Port-wide Maintenance Campaign (260,000 m³)

A Port-wide maintenance dredging campaign was modelled to indicate the potential cumulative effects on turbidity percentiles and deposition rates. The volume removed by dredging was approximately 260,000 m³, which represents the typical annual dredged material volume, consistent with the analysis presented in the Maintenance Dredging Strategy for Great Barrier Reef ports (Department of Transport and Main Roads, 2016). A representative maintenance dredging program was derived from analysis of Port of Gladstone maintenance dredging logs for the TSHD *Brisbane*. Dredging plume loads were derived based on previous work which compared modelled plume characteristics with field measurements of suspended sediment concentrations. This is consistent with previous maintenance dredging modelling undertaken for the Port of Gladstone (BMT WBM, 2017b).

5.2.6.2 Flood Event

Catchment loads for the 2013 flood event (annual exceedance probability approximately 1 in 100) were applied to the model to investigate the potential cumulative effects on turbidity percentiles. These catchment loads were derived from previous catchment modelled work completed in Gladstone (BMT WBM, 2015b). The simulation was carried out over a period of 73 days.

The major freshwater inflows included in the flood event modelling are shown in Figure 5-5 (smaller catchment sources were also included in the modelling). These can be contrasted with the typical flow rates used in the assessment period (refer Figure 4-6).



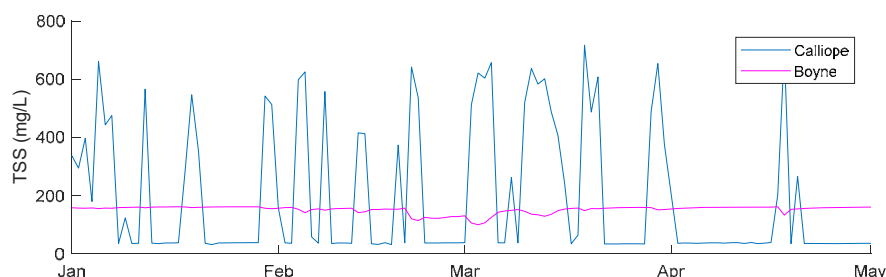


Figure 5-5 2013 Flood Flow Rates and TSS Concentrations (Major Catchments)

5.3 Impact Assessment Methodology

The potential effects of dredging were assessed based on the modelled temporary increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredging-related signals were resolved in the predictive model, which allows for an understanding of how significant the dredging contribution is in relation to ambient conditions.

The water column turbidity impacts associated with dredging-related suspended sediment were derived by converting the modelled TSS levels into an equivalent turbidity value using an established relationship (refer to Figure 2-32). Depth-averaged turbidity values are presented here since they are most relevant to assessing potential ecological impacts due to the reduction in seabed Photosynthetically Active Radiation (PAR) (i.e. light levels on the seabed). Sedimentation impacts were derived from the daily rate of change in bed sediment mass. The adopted sedimentation rate units are mg/cm²/day.

The predicted effects of dredging have been assessed using two different presentation techniques:

- Time series at sensitive receptor sites; and
- Spatial plots based on percentile analysis.

The scope of this modelling report does not cover the entire impact assessment process, however, it does supply (and describe) some of the impact assessment inputs that have been used in the water quality, marine ecology and coastal process impact assessment chapters.

5.3.1 Time Series Analysis

Time series provide a simple way to present turbidity increases due to dredging at predetermined points of interest. Having simulated both dredging and ambient sediment processes, the time series show both these contributions to the total signal and in doing so provide important information on the relative magnitude of the dredging-related signal. Turbidity time series plots for selected locations are provided in Appendix I.

5.3.2 Percentile Analysis

Spatial representations of the dredging impacts were based on percentile exceedance analysis of the model results and were derived by applying a moving 14-day analysis window over the simulation period. The 14-day window period is somewhat arbitrary, but in a physical hydrodynamic context

represents the approximate duration of one spring-neap tidal cycle, while in an ecological context it is a meaningful timescale for assessing impacts to some key sensitive receptors in the area (e.g. intertidal seagrass meadows). The 14-day analysis window was moved forward by 5-day increments from the start to the finish of the simulation period, to ensure full coverage of the simulation.

The percentile impact plots correspond to the predicted increase in turbidity/sedimentation over ambient conditions that are attributable to the dredging. Impacts at each percentile level were calculated for every 14-day window during the simulation, and the average increase over all windows at each location in the model domain is presented. It is important to note that the presented turbidity percentile plots do not represent the plume extent at any one particular instant in time, they represent statistical analysis of the model outputs.

Percentile values considered in this report are 95th and 50th, which correspond to exceedance durations of 17 hours (5%) and 7 days (50%), respectively for the 14-day window. The highest percentiles correspond to relatively short-lived increases in turbidity/sedimentation, while the lower percentiles correspond to sustained (but temporary) increases.

The spatial percentile exceedance dredging impact plots are presented in tandem with the equivalent modelled ambient percentile statistics, calculated as the average over all 14-day windows during the simulation period. This allows the increases in turbidity/sedimentation due to dredging to be seen relative to the modelled ambient conditions.

Key features of the moving window percentile analysis include:

- Consideration of a range of impact durations from short to long term.
- Can be applied to a long term program and capture periods of high intensity versus low intensity impacts.
- A similar analysis applied to the baseline data can quantify the ambient conditions, including natural variability across different periods. This can be used to derive meaningful thresholds for the potential impacts.

More than 12 months of baseline turbidity monitoring was analysed to derive contour limits for the presentation of the percentile impact plots that are meaningful at specific sites. It should be noted that different thresholds (and therefore different contour limits) are appropriate for the different percentiles.

It is important to note that the percentile plots presented in this report are not 'snapshots' of the levels of turbidity in the Port, and the impact plots do not represent what the visible plume might look like at any one time. They are representations of turbidity statistics over long periods of time, and the impact plots show the potential changes to those statistics.

To illustrate what actual plumes could look like from above, Figure 5-6 shows an aerial photograph of a maintenance dredging plume in Gladstone together with a modelled plume 'snapshot' at the same point in time.

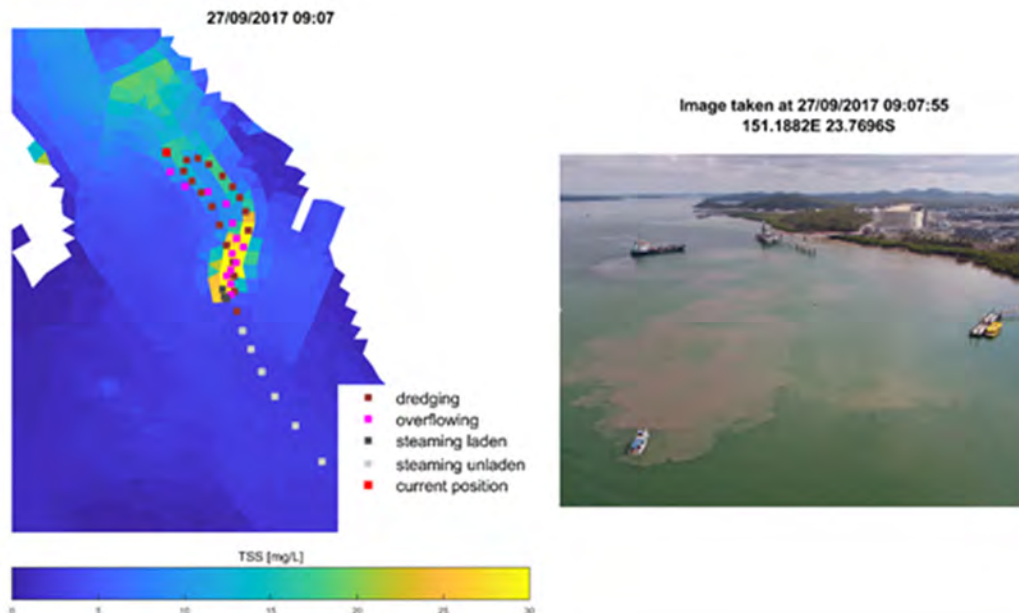


Figure 5-6 Modelled Suspended Sediment Plume in Gladstone (Left) Compared to Aerial Photograph (Right)

5.3.3 Impact Zone Derivation

Project-specific threshold values were developed to assess potential impacts to marine water quality and ecologically sensitive areas (refer to Project EIS Chapter 8 (water quality) and Chapter 9 (nature conservation), respectively). These impact predictions are presented as 'zones of impact' as per the Commonwealth EIS Guidelines, and are derived using the percentile exceedance plots described above. The zones of impact, which are generally based on dredging environmental assessment guidelines produced by the WA EPA (2011), include the following:

- Zone of High Impact = Excess turbidity from dredging activities most likely to cause water quality to deteriorate beyond natural variation.
- Zone of Moderate Impact = Excess turbidity from dredging activities likely to cause water quality to deteriorate beyond natural variation.
- Zone of Low Impact = Excess turbidity from dredging activities may cause water quality to deteriorate beyond natural variation.
- Zone of Influence = Extent of detectable plume (that could be measured by instrumentation), but with no predicted ecological impacts.

A conceptual design of the zones of impact is shown in Figure 5-7, and a schematic representation of the impact zones is shown in Figure 5-8. The zone of low impact is included within the zone of influence in Figure 5-7 and Figure 5-8.

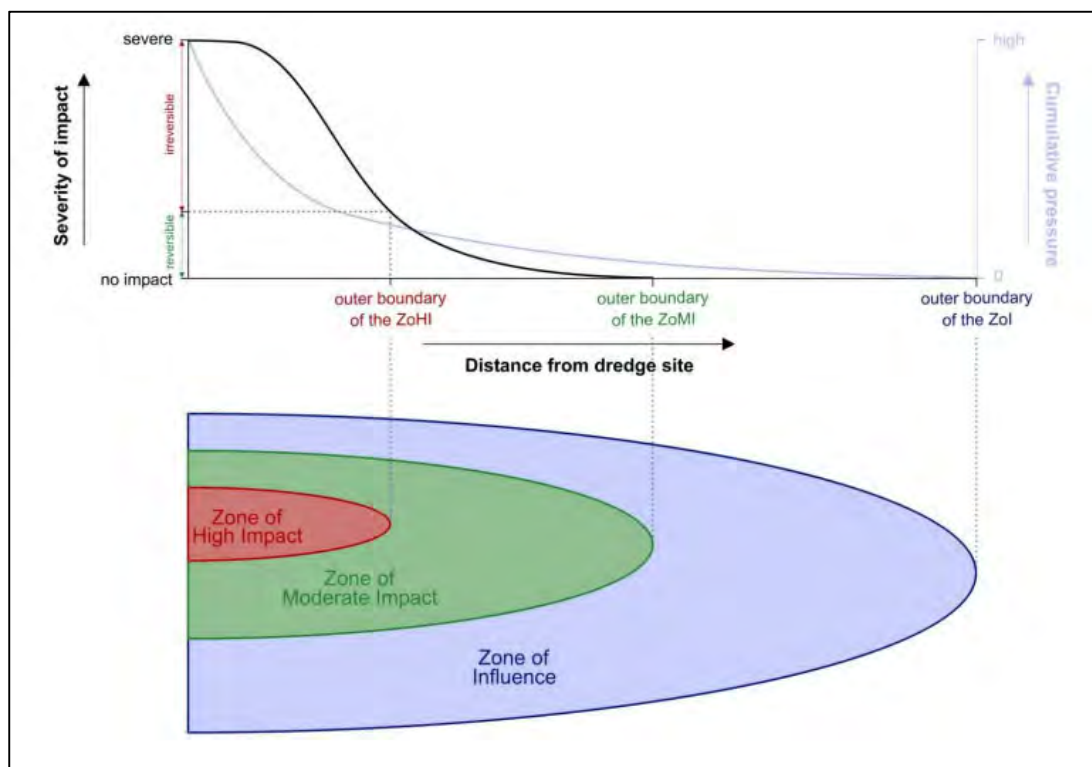


Figure 5-7 Concept Design of Impact Zones (from WA EPA 2011)

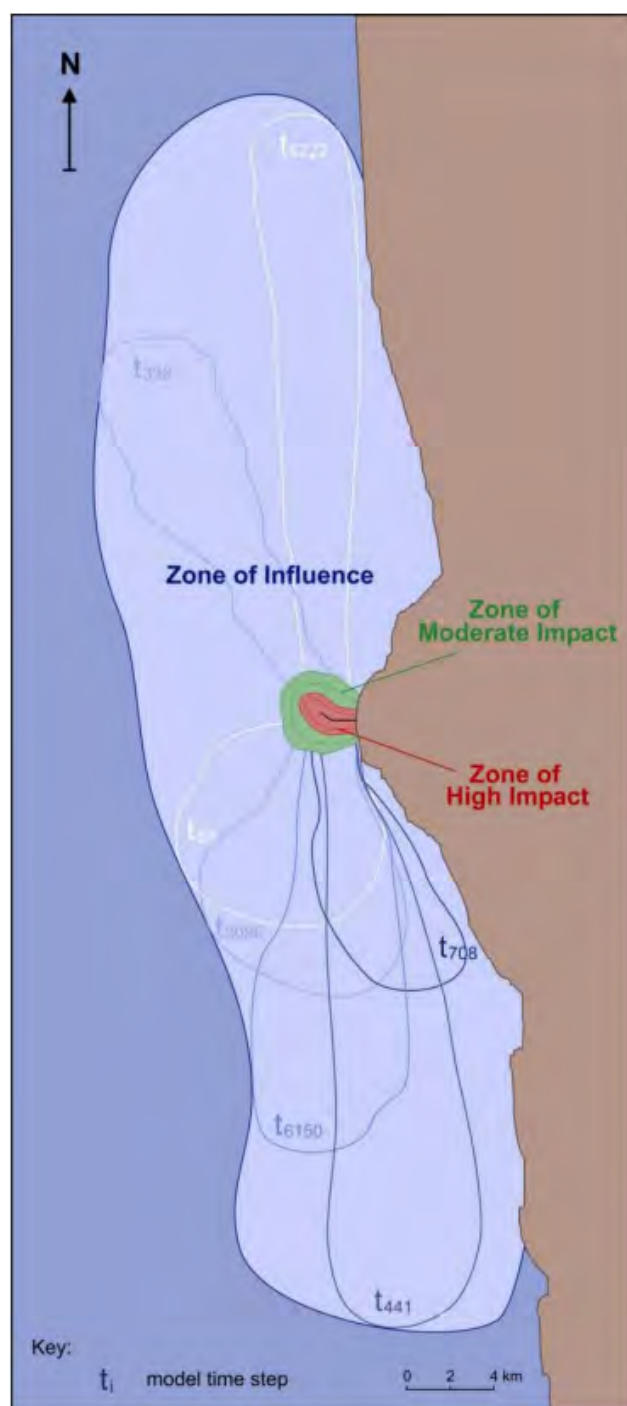


Figure 5-8 Schematic Representation of Spatially Based Impact Zonation Scheme for Representing Dredge Related Impacts (from WA EPA 2011)

To determine the threshold values to delineate the zones of impact, a combination of referential and biological tolerances methods was used. This entailed using baseline water quality monitoring data to set initial threshold values (referential method). These values were then compared to biological tolerances from literature values as a 'reality check' to see if the threshold values are biologically meaningful.

5.3.3.1 13-Month Baseline Water Quality Data

As described in Section 1.1, continuous turbidity data (and other parameters) were collected over a 13-month period (May 2014 to June 2015) at eight sites. The locations of these sites are shown in Figure 2-7 and include:

- P2B/WB50 (surface);
- P5/MH30 (surface);
- CD1 (surface and benthic);
- CD2 (surface and benthic);
- CD3 (surface and benthic);
- CD4 (surface and benthic);
- CD5 (surface and benthic); and
- QE3 (surface).

The 13-month monitoring data set underwent a quality control process whereby data points that were obviously not valid (due to fouling or other malfunction) were removed.

Further information in regard to the 13-month baseline water quality monitoring program is provided in the Project EIS Chapter 8 (water quality) and Project EIS Appendix H1.

5.3.3.2 Threshold Values

As the long term data shows variability in turbidity among sites during the same time period, site-specific thresholds were deemed more appropriate than a 'one size fits all' approach. To determine initial impact threshold values, the 13-month baseline water quality monitoring data set was analysed and percentile curves were produced. These percentile curves provide an indication of magnitude of turbidity and combined duration/frequency metrics for a range of conditions.

The 13-month baseline data was analysed over a moving 14-day window period to give a range of percentile values over different periods. The 14-day window period is somewhat arbitrary but in a physical hydrodynamic context represents the approximate duration of two consecutive spring-neap tidal cycles, while in an ecological context it is a meaningful timescale for assessing impacts to some key sensitive receptors in the area (i.e. dominant seagrass *Halophilophila ovalis*). The 14-day moving window analysis was undertaken by moving the 14-day window by 5-day increments over the entire monitoring period (approximately 77 different 14-day periods). This method provides an indication of

natural variability around each percentile value and provides context for excess turbidity from dredging.

As an example, Figure 5-9 shows the percentile curves for data collected at Site P2B. This shows the natural variability measured around the median (50th percentile) and other percentile values. The x-axis in Figure 5-9 represents the different percentile values extracted from the moving 14-day window analysis from frequently exceeded on the left to rarely exceeded on the right. The different curves are statistics representing the variability of the turbidity percentiles across the different 14-day periods (making up the 13-month baseline monitoring period). The lower curve represents the least turbid conditions during any window within the 13-month period, while the upper limit is the result for the windows with the most turbid conditions. The solid red line is the mean of the different 14-day window conditions.

Percentile curves for all monitoring sites are included in Appendix J.

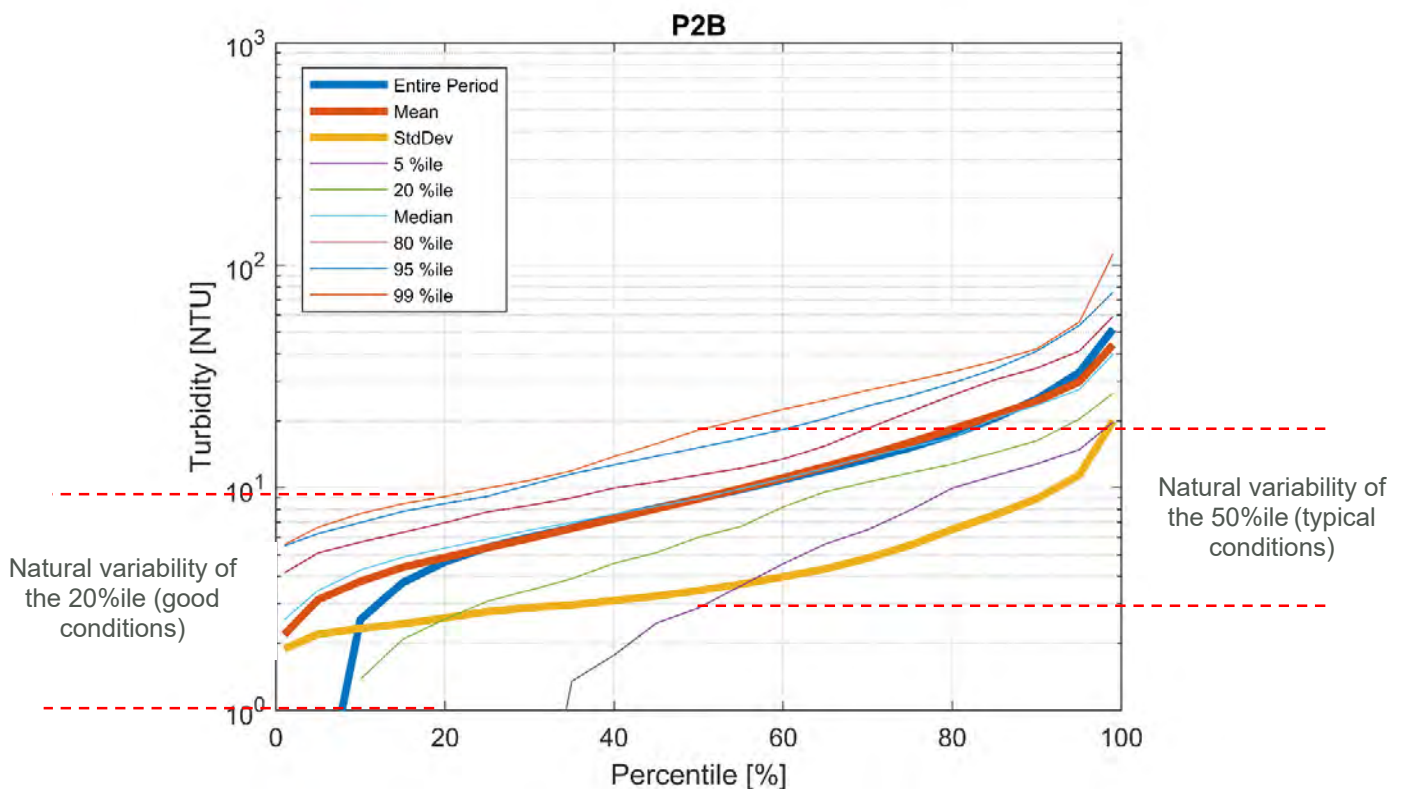


Figure 5-9 Example Summary Analysis of Baseline Data for Site P2B

Threshold values were derived from these percentile curves based on the natural variability around the 50th percentile (average conditions), 20th percentile (good conditions – neap tides / low winds and waves) and the 80th percentile (poor conditions – spring tides / moderate to high wind and waves). Therefore, this method considers both short term and sustained impacts.

A description of the threshold values for the three zones of impact and how they relate to the natural variability is provided in Table 5-3. The approach used to determine the threshold levels involved using the standard deviation from the natural background mean of each percentile over all of the 14-day windows (i.e. 20th, 50th and 80th percentiles). This is a similar approach to the one developed by Orpin *et al.* (2004) to assess impacts from construction-related turbidity increases in Townsville. Orpin *et al.* (2004) suggested that one standard deviation from ambient conditions could be used as a possible conservative upper limit of an acceptable increase in turbidity. Orpin *et al.* (2004) noted that the standard deviation of natural turbidity levels was considered to be a reasonable and convenient envelope within which an allowable construction-related increase could occur. If construction-related turbidity remained within one standard deviation of natural variation, Orpin *et al.* (2004) suggested it would not be detectable over and above the natural variability. Extending this method out, threshold levels for the 'zone of medium impact' and the 'zone of high impact' were determined using two and three standard deviations from the mean, respectively. These levels were also tested against biological tolerance literature values (refer Section 5.3.4).

The 'zone of influence' was defined as the probable maximum extent of detectable plumes due to the proposed dredging. Turbid plumes were assumed to become detectable by instrumentation once they were approximately 20-30% above background conditions. To determine the extent of this zone, the following criteria were used (with any one criterion to be satisfied):

- 0.5 NTU above 50th percentile conditions;
- 2 NTU above 80th percentile conditions;
- 5 NTU above 95th percentile conditions; or
- 10 NTU above 99th percentile conditions.

Included in Table 5-3 are biological tolerance literature values for seagrass in other regions. Only biological tolerances for seagrass are included as corals are too variable among species and sites to define at this stage. As the seagrass tolerances are expressed as light requirements, a relationship between PAR and turbidity was used to convert light requirements to turbidity.

Further to the conservative nature of the literature values, it is acknowledged (including by regulators and scientists) that there are uncertainties regarding the responses of seagrass to high turbidity values, which is used here as a proxy for light. Therefore, the biological tolerance literature values are only used as a means for cross-checking potential ecological relevance of changes to turbidity values.

Table 5-3 Description of Threshold Values

Impact Zone	Referential (Water Quality)	Biological Tolerances (Seagrass)
Zone of High Impact	Excess turbidity <i>most likely</i> to cause total turbidity to go beyond natural variation Threshold value = excess turbidity greater than three standard deviations from the natural background mean	<i>Zostera muelleri</i> subsp. <i>capricorni</i> – 14 day rolling average of <6 mol photons m⁻² day⁻¹ over 28 days <i>Halodule uninervis</i> – 14 day rolling average of <5 mol photons m⁻² day⁻¹ over 40 days <i>Halophila</i> spp. – 7 day rolling average of <2 mol photons m⁻² day⁻¹ over 14 days
Zone of Moderate Impact	Excess turbidity <i>likely</i> to push total turbidity beyond natural variation Threshold value = excess turbidity greater than two standard deviations from the natural background mean	<i>Zostera muelleri</i> subsp. <i>capricorni</i> – 14 day rolling average of <6 mol photons m⁻² day⁻¹ over 21 days <i>Halodule uninervis</i> – 14 day rolling average of <5 mol photons m⁻² day⁻¹ over 21 days <i>Halophila</i> spp. – 7 day rolling average of <2 mol photons m⁻² day⁻¹ over 10 days
Zone of Low Impact	Excess turbidity <i>may</i> push total turbidity beyond natural variation Threshold value = excess turbidity greater than one standard deviation from the natural background mean	<i>Zostera muelleri</i> subsp. <i>capricorni</i> – 14 day rolling average of <6 mol photons m⁻² day⁻¹ <i>Halodule uninervis</i> – 14 day rolling average of <5 mol photons m⁻² day⁻¹ <i>Halophila</i> spp. – 7 day rolling average of <2 mol photons m⁻² day⁻¹
Zone of Influence	Extent of detectable plume (as measured by instrumentation) but no predicted ecological impacts Turbidity related to dredging activities exceeds: - 0.5 NTU above 50th percentile conditions - 2 NTU above 80th percentile conditions - 5 NTU above 95th percentile conditions - 10 NTU above 99th percentile conditions	<i>Zostera muelleri</i> subsp. <i>capricorni</i> – 14 day rolling average of >6 mol photons m⁻² day⁻¹, however less than ambient <i>Halodule uninervis</i> – 14 day rolling average of >5 mol photons m⁻² day⁻¹, however less than ambient <i>Halophila</i> spp. – 7 day rolling average of >2 mol photons m⁻² day⁻¹, however less than ambient

The threshold values for each zone of impact at each monitoring site were derived by analysis of the turbidity data using referential methods. These values represent turbidity above background levels, and are provided in Table 5-4. It should be noted that with the use of these impact threshold values, an assumption has to be made in regard to what constitutes 'background turbidity'. For the purposes of this impact assessment, background turbidity is assumed to be the mean turbidity of background data at each percentile at each location.

Modelling of Dredging Activities

Table 5-4 Impact Threshold Values (Above Background) for each Monitoring Site

Impact Zone	Description	Method	Percentile	Descriptor	CD1	CD2	CD3	CD4	CD5	P2B	P5	QE3
					Turbidity Threshold Values (NTU) - above background							
Zone of High Impact	Excess turbidity <i>most likely</i> pushes total turbidity beyond natural variation	3 x standard deviations from 20%ile mean	20%ile	Exceeded 80% of the time	4	5	6	4	2	8	3	12
		3 x standard deviations from 50%ile mean	50%ile	Exceeded 50% of the time	7	7	9	5	4	10	5	13
		3 x standard deviations from 80%ile mean	80%ile	Exceeded 20% of the time	12	12	16	8	8	20	13	20
Zone of Moderate Impact	Excess turbidity <i>likely</i> pushes total turbidity beyond natural variation	2 x standard deviations from 20%ile mean	20%ile	Exceeded 80% of the time	3	3	4	3	2	5	2	8
		2 x standard deviations from 50%ile mean	50%ile	Exceeded 50% of the time	5	5	6	4	3	7	4	9
		2 x standard deviations from 80%ile mean	80%ile	Exceeded 20% of the time	8	8	10	5	6	13	8	13
Zone of Low Impact	Excess turbidity <i>may</i> push total turbidity beyond natural variation	One standard deviation from 20%ile mean	20%ile	Exceeded 80% of the time	1	2	2	1	1	3	1	4
		One standard deviation from 50%ile mean	50%ile	Exceeded 50% of the time	2	2	3	2	1	3	2	4
		One standard deviation from 80%ile mean	80%ile	Exceeded 20% of the time	4	4	5	3	3	7	4	7
Zone of Influence	Full extent of detectable plumes (including resuspension)	Dredging-related turbidity exceeds 0.5 NTU	50%ile	Exceeded 50% of the time	0.5							
		Dredging-related turbidity exceeds 2 NTU	80%ile	Exceeded 20% of the time	2							
		Dredging-related turbidity exceeds 5 NTU	95%ile	Exceeded 5% of the time	5							
		Dredging-related turbidity exceeds 10 NTU	99%ile	Exceeded 1% of the time	10							

5.3.4 Testing of Impact Zones

To test whether the zones of impact developed using turbidity thresholds in Table 5-4 are biologically meaningful, the turbidity thresholds were added to actual benthic PAR monitoring data (June 2014-May 2015) for intertidal sites containing coastal seagrass (i.e. *Zostera*) and monitored by TropWater. These sites included Pelican Banks South and Wiggins Island. Data from subtidal sites where coincident turbidity and benthic PAR data were collected (i.e. sites CD1 to CD5), along with surface PAR data at these sites, were used to develop a light attenuation coefficient (K_d) for the study area. This K_d value was used to convert turbidity to benthic PAR and vice versa at the intertidal seagrass sites.

The aim of undertaking this analysis was to assess the amount of benthic PAR available to this seagrass area if additional turbidity as per the turbidity impact thresholds was added to the measured PAR data. To achieve this, the time series benthic PAR was converted to time series turbidity using the light attenuation/turbidity correlation developed for the study area. Once the additional turbidity (corresponding to the threshold value) was added onto this time series it was converted back to benthic PAR using the same light attenuation/turbidity correlation.

The aim was to simulate a hypothetical scenario whereby a dredger would be operating with turbid plumes being created at these threshold values (note that in reality, a dredger would not be operating for this entire period). An outcome of this analysis, for example, should be that PAR available to seagrass after adding the low impact turbidity threshold should only result in predicted low impacts and not moderate or high impacts.

The 50th percentile threshold values for site P5 (near to Pelican Banks) and P2B (near to Wiggins Island) from Table 5-4 were used in this analysis as this allowed a relatively simple addition of excess turbidity to the time series PAR data.

Two week rolling averages of the derived PAR data are presented in Figure 5-10, which also shows baseline monitoring data (actual recorded data). As *Zostera* is the dominant seagrass species found in these intertidal areas, the results were compared to the biological tolerances for *Zostera* in Table 5-3. The results indicate that:

- Using the low impact zone threshold (2-3 NTU depending on the site), benthic PAR would remain above the *Zostera* light requirement at both sites, except for a short periods of time less than 14 days duration.
- Using the moderate impact zone threshold (4-7 NTU depending on the site), there would be periods over 21 days at both sites when benthic PAR would be below the *Zostera* light requirement. However, benthic PAR would also remain above the light requirement for extended periods, especially during the seagrass growing season (July to December).
- Using the high impact zone threshold (5-10 NTU depending on the site), the benthic PAR at both sites would mostly remain below the *Zostera* light requirement for longer than 28 days – this would potentially result in loss of seagrass at these sites (as expected of this zone).

Therefore, based on this analysis, the zones of impact derived using the turbidity threshold values in Table 5-4 are considered to be suitable for impact assessment purposes.

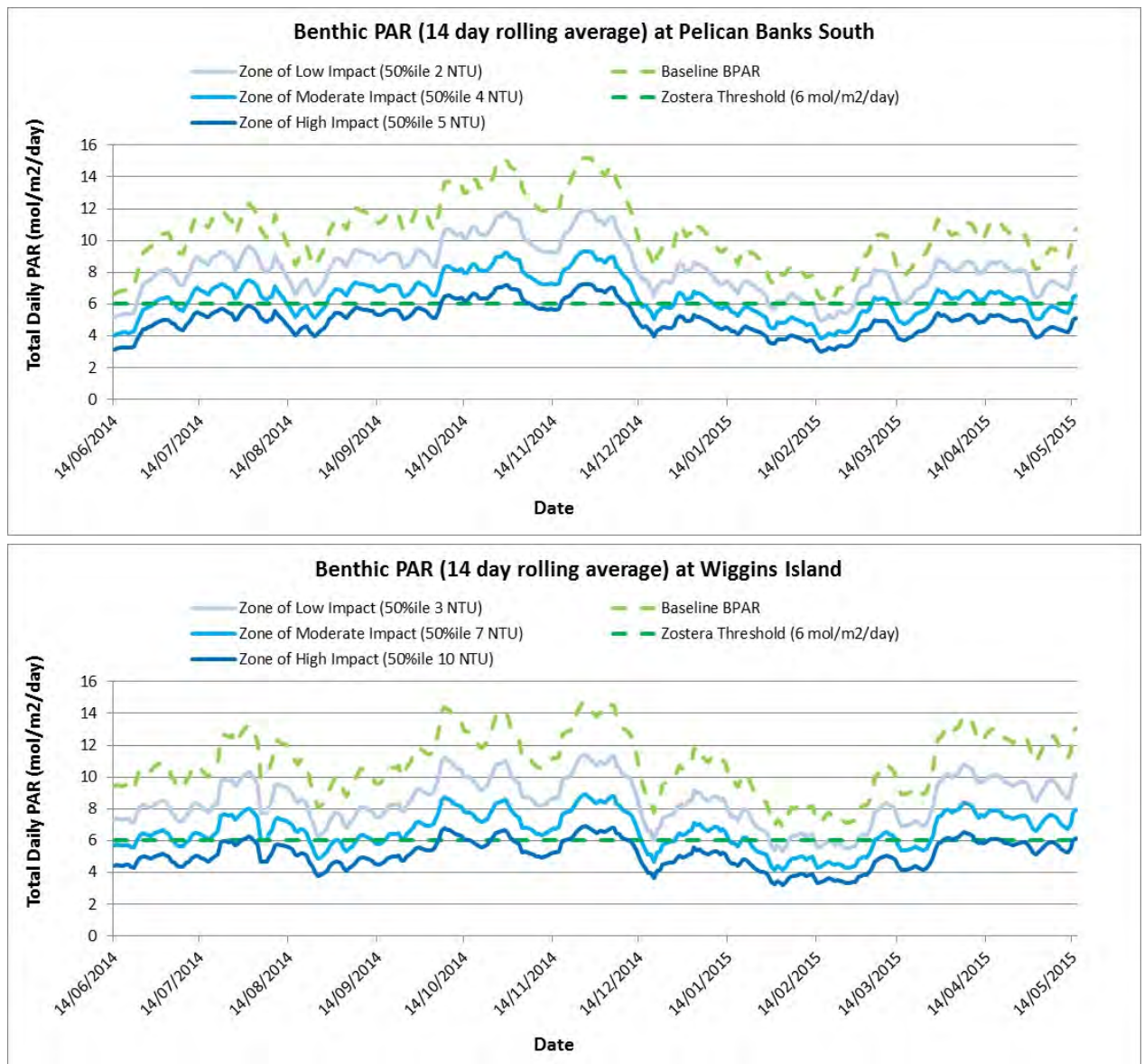


Figure 5-10 Total daily PAR (mol/m²/day as 14 day rolling average) at Pelican Banks South (top) and Wiggins Island (bottom) showing baseline (actual monitoring data) and addition of impact zone thresholds

5.4 Modelling Results

5.4.1 Overall Capital Works Program

The expected operations of all three stages of the dredging program were simulated in the numerical model, using tidal and atmospheric boundary conditions for the period 20 June 2014 to 13 November 2015 (a period that includes large spring tides and is representative of typical conditions within the Port of Gladstone – refer to Section 4.2).

The modelled effects of the dredging program on the percentiles of the depth-averaged turbidity and bottom 1 m turbidity are presented in Figure 5-11 to Figure 5-14. These figures give an overall indication of the spatial distribution of dredging impacts characteristic of the dredging program in its entirety, including all sources of suspended sediment. The average change in the turbidity percentiles was calculated for each stage of the dredging campaign, and the overall impact at each location in the model was taken as the largest predicted impact from any of the project stages. These impact figures are used as the basis for derivation of the zones of influence/impact results in Section 5.4.2. The spatial turbidity percentile impacts for each stage of the campaign are provided in Appendix H.

It is important to note that the colours used to demonstrate the changes in the turbidity for the 95th percentile and 50th percentile plots use different scales, therefore the specific colour used in the figures does not represent the same level of turbidity for every modelled scenario (i.e. each figure needs to be interpreted with respect to the specific NTU scale colours given at the bottom of each figure).

Example time series of turbidity (dredging-related and total (including background)) at five of the EIS water quality monitoring sites (sites CD1 to CD5 in Figure 2-7) are presented in Appendix I. These locations were chosen because they provide some indication of the relative contribution of dredging-related resuspension to the turbidity level in offshore areas.

The top panel of Figure 5-11 shows the ambient (background) 95th percentile depth-averaged turbidity throughout the model domain, averaged over all of the 14-day windows during the simulation period. The middle panel of Figure 5-11 shows the total (ambient plus dredging) 95th percentile depth-averaged turbidity throughout the model domain, averaged over all of the 14-day windows during the simulation period. The bottom panel shows the average change in the 95th percentile depth-averaged turbidity due to the dredging activity (indicating the expected spatial impact to the turbidity level for 0.7 days out of every 14 days during dredging). The modelling results indicate that some short term increases to turbidity levels are expected throughout the Port area, with the highest increases in areas outside the Port entrance where wave activity can resuspend dredged sediment after initial deposition. Note that the ambient (background) turbidity level is relatively high throughout the study area, as seen in the top panel of Figure 5-11.

The top panel of Figure 5-12 shows the average ambient 50th percentile turbidity throughout the model domain over all of the 14-day windows during the simulation period. The middle panel of Figure 5-12 shows the average total (ambient plus dredging) 50th percentile turbidity throughout the model domain over all of the 14-day windows over the simulation period. The bottom panel shows the average change in the 50th percentile turbidity due to the dredging activity (indicating the expected impact to the turbidity level for 7 days out of every 14 days during dredging). The modelling results indicate minor sustained impacts to the turbidity level within the Port, and higher sustained (but

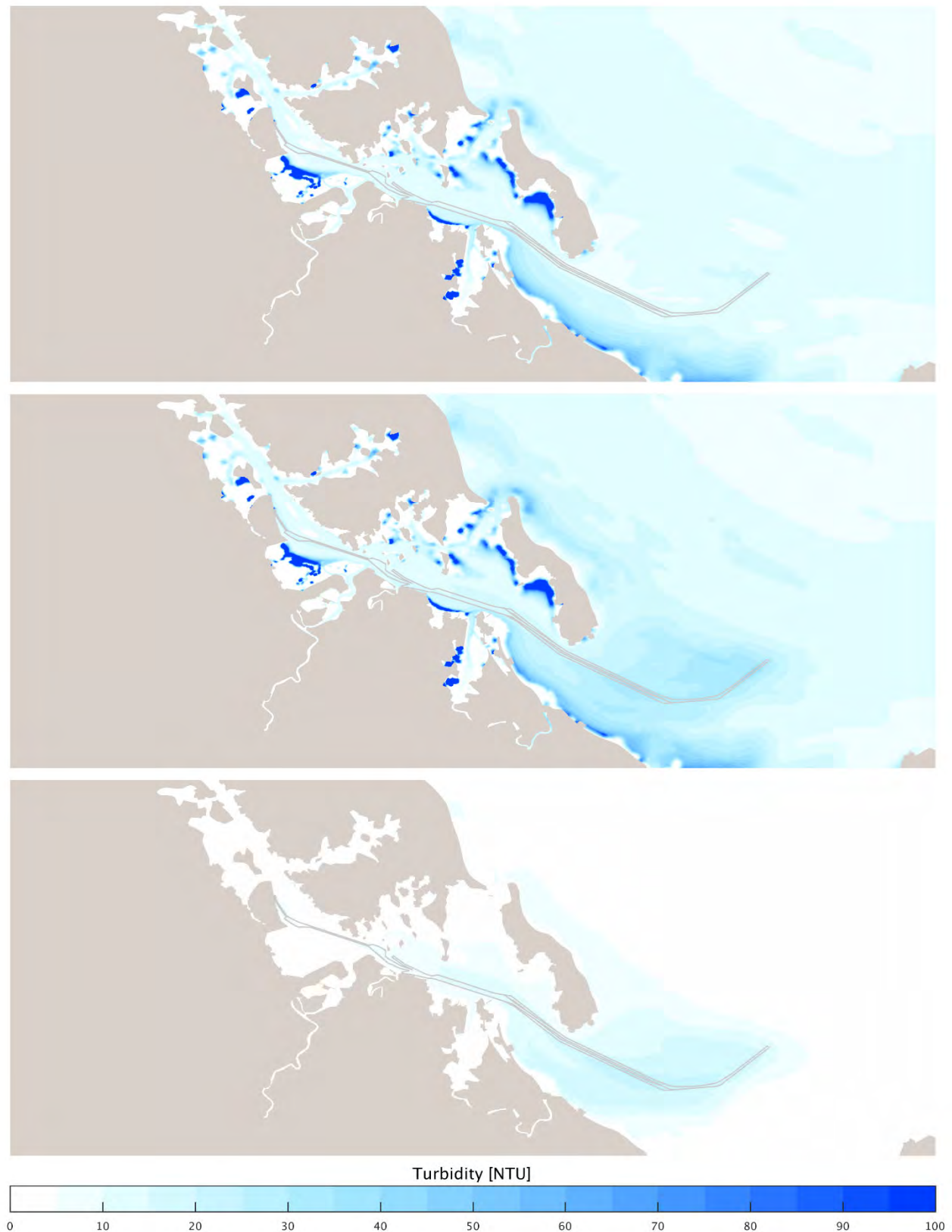
temporary) effects in the vicinity of the area to be dredged and further offshore (due to resuspension activity).

Figure 5-13 and Figure 5-14 show the modelled impacts to the 95th and 50th percentile turbidity levels in the bottom 1 m of the water column due to the dredging activity. The patterns of the spatial impacts are similar, with larger magnitudes.

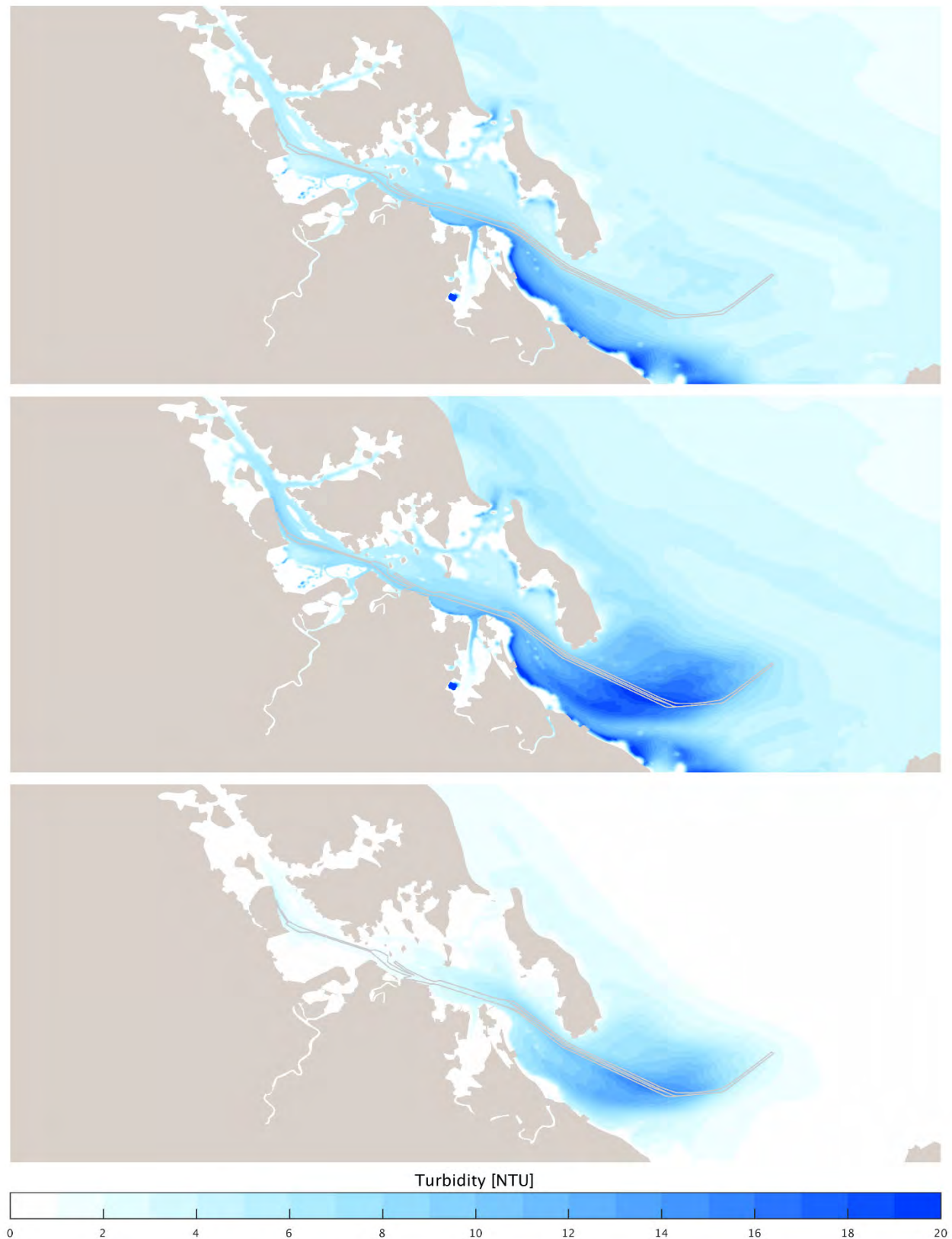
The top panel of Figure 5-15 shows the ambient 95th percentile deposition rate throughout the model domain, averaged over all of the 14-day windows during the simulation period. The middle panel shows the average total (ambient plus dredging) 95th percentile deposition rate throughout the model domain. The bottom panel shows the average change in the 95th percentile deposition rate due to the dredging activity (indicating the expected impact to the deposition rate for 0.7 days out of every 14 days during dredging). Some minor increases in short term deposition rate are noted in the central Port area.

The top panel of Figure 5-16 shows the ambient 50th percentile deposition rate throughout the model domain, averaged over all of the 14-day windows during the simulation period. The middle panel shows the average total (ambient plus dredging) 50th percentile deposition rate throughout the model domain. The bottom panel shows the average change in the 50th percentile deposition rate due to the dredging activity (indicating the expected impact to the deposition rate for 7 days out of every 14 days during dredging). Some very minor sustained (but temporary) increases in the deposition rate are noted within the Port.

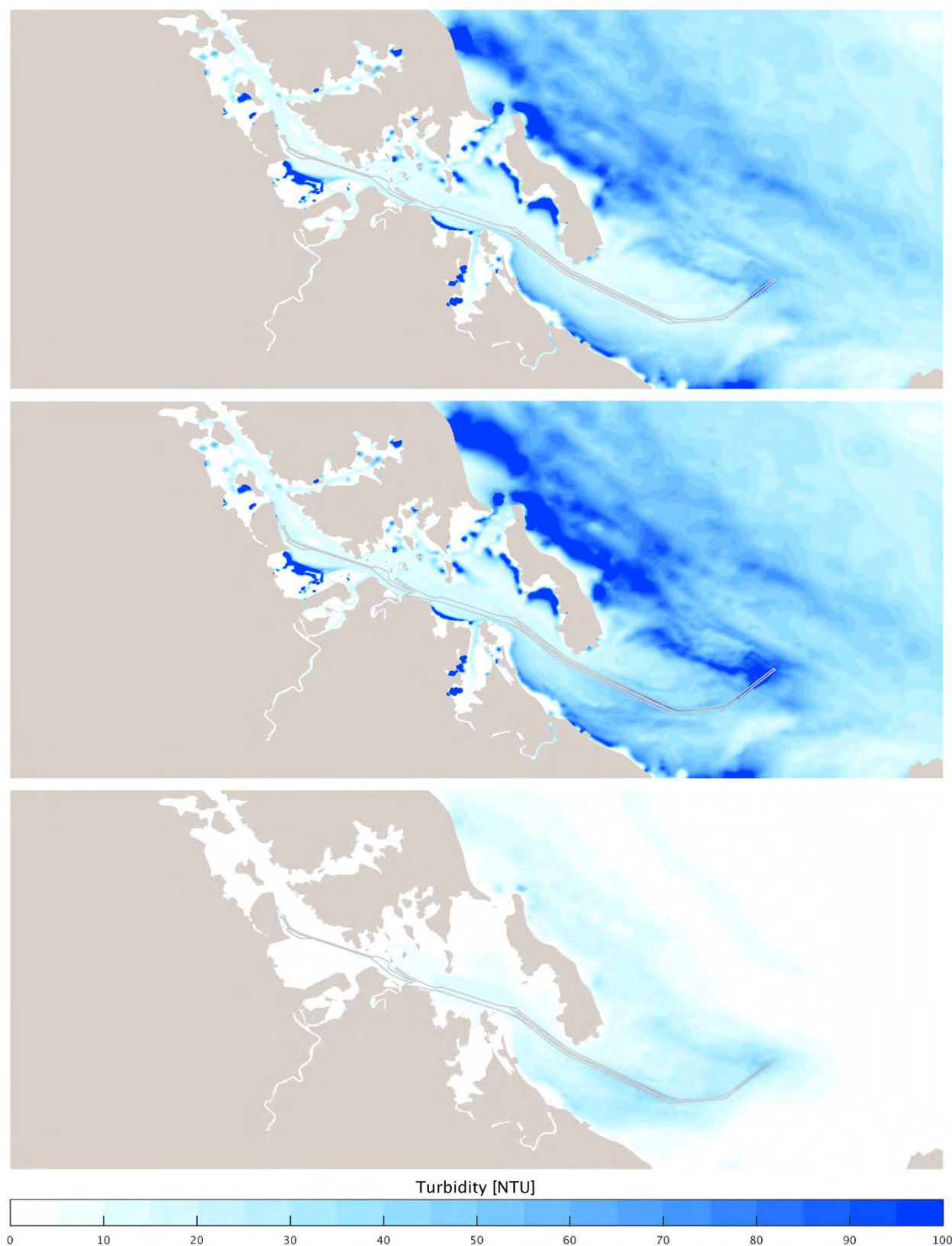
The net total deposition of dredged sediment at the completion of the dredging campaign is shown in Figure 5-17. The highest modelled accumulation of dredged sediment is in the central Port area. The model results include some small areas with high net deposition, which may be artefacts.



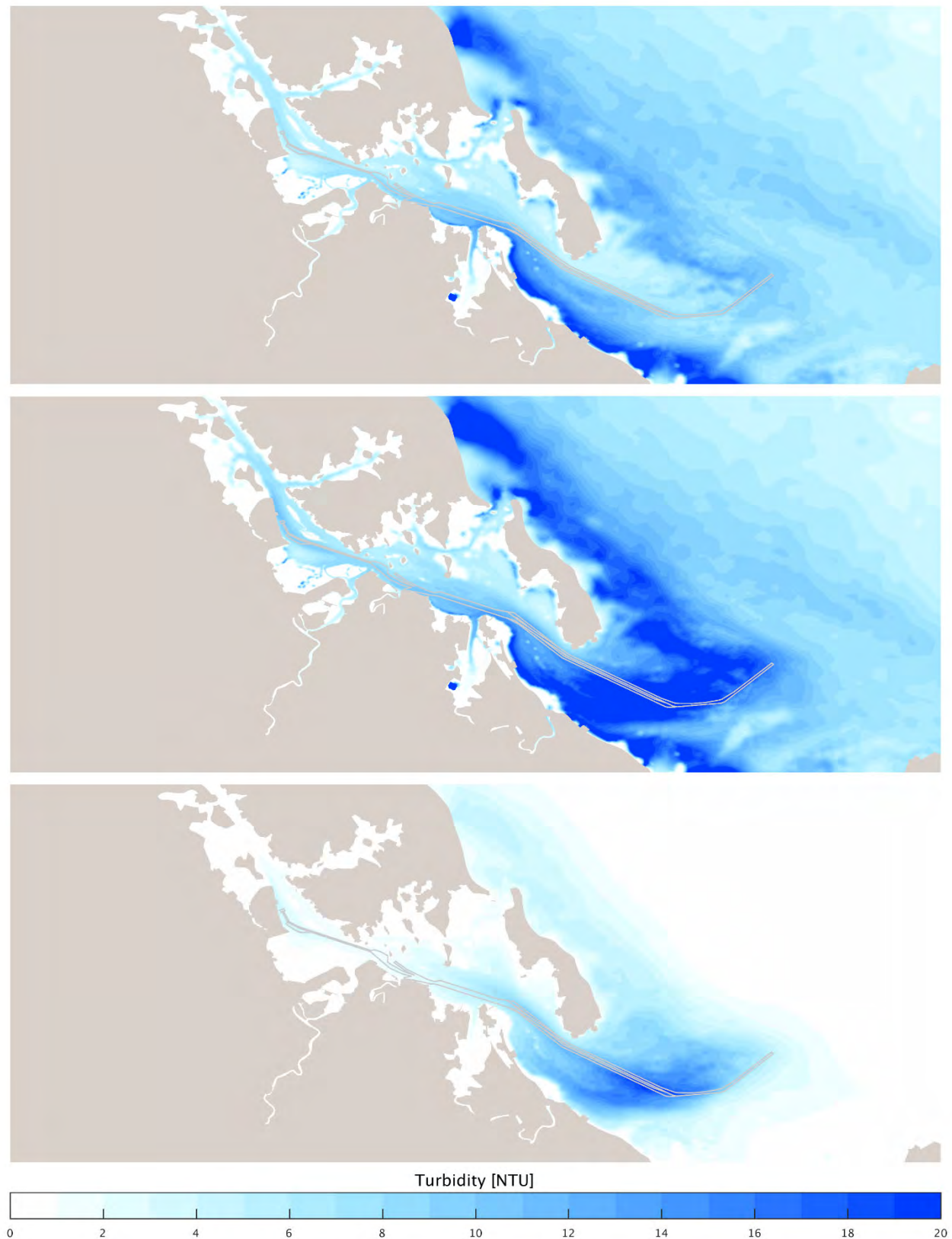
**Figure 5-11 95th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**



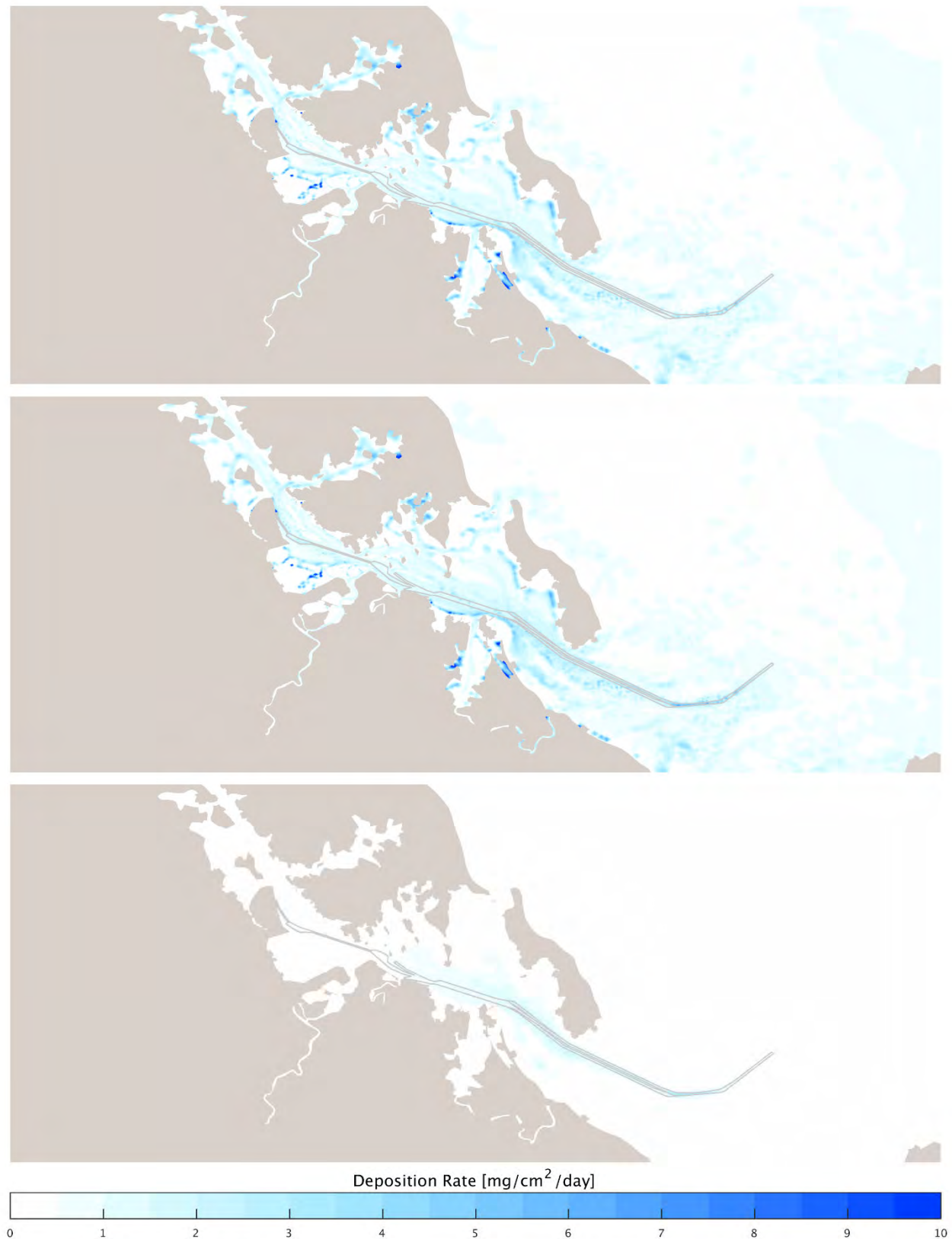
**Figure 5-12 50th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**



**Figure 5-13 95th Percentile of the Bottom 1m Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**



**Figure 5-14 50th Percentile of the Bottom 1m Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**



**Figure 5-15 95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**



**Figure 5-16 50th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Overall Dredging Campaign**

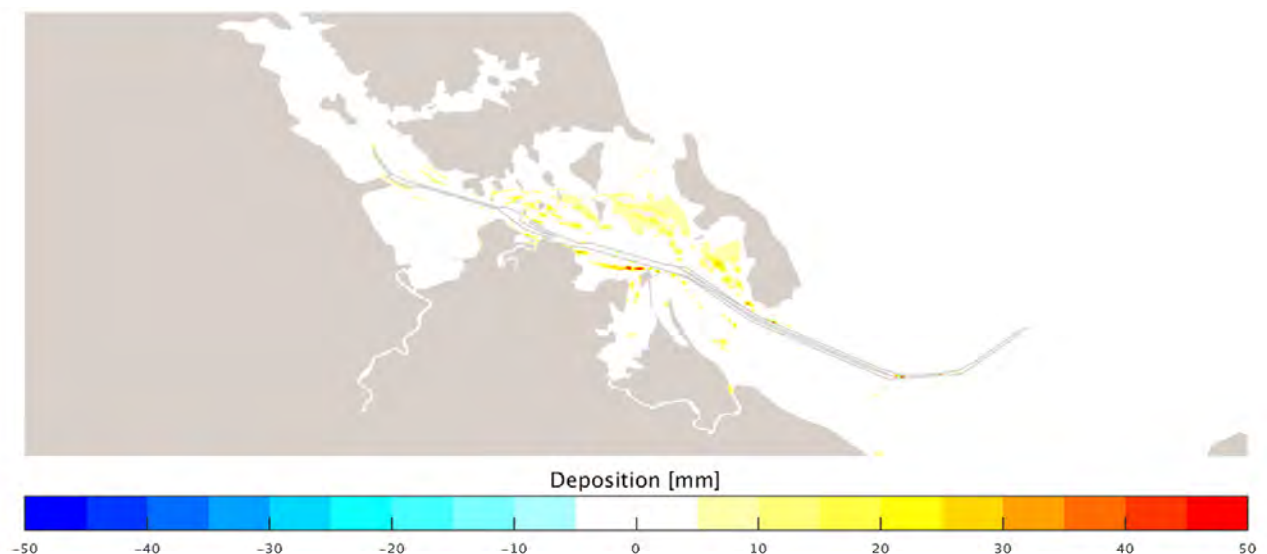


Figure 5-17 Net Deposition of Dredged Sediment at Completion of Dredging

5.4.2 Zones of Impact Results for Suspended Sediment

To determine zones of impact as described in Section 5.3.3 and below, the site-specific impact threshold values from baseline monitoring data (Section 5.3.3.2) were interpolated spatially across the study area to produce a grid of threshold values. These threshold grids were then analysed against the modelled turbidity impact results using GIS mapping software. This produced impact zone maps which indicate areas where modelled turbidity impact (at each percentile) is higher than the relevant impact threshold value. The impact zone map for the overall capital works dredging program is shown in Figure 5-18, with impact zones briefly described as follows:

- Zone of Influence – full extent of detectable plumes, but no ecological impacts.
- Zone of Low Impact – water quality may be pushed beyond natural variation potentially resulting in sub-lethal impacts to ecological receptors.
- Zone of Moderate Impact – water quality is likely be pushed beyond natural variation potentially resulting in some mortality with recovery < 12-24 months.
- Zone of High Impact – water quality is very likely to be pushed beyond natural variation potentially resulting in mortality of ecological receptors with recovery >24 months.

Figure 5-18 indicates that the zone of influence (i.e. extent of detectable plumes, but no ecological impact) extends northwards along the coast of Curtis Island to Cape Capricorn and through the Western Basin into the Narrows. To the south east the zone of influence extends beyond Seal Rocks but not as far as Richards Point. The zone of influence is larger in the offshore area due to less turbid ambient conditions in this area (i.e. plumes are easier to detect above background).

At the areas to be dredged, the zone of high impact is within the immediate vicinity of the channel duplication dredging area and extends approximately 1 km in a northwest direction of the Gatcombe Channel and approximately 2 km southeast from the Golding Cutting Channel. The zone of high impact also extends 6-7 km in both east and west directions from the Golding Cutting Channel (refer Figure 5-18). The zone of low impact extends northwards along the coastline of Facing Island and

into the central part of the Port. The largest impact is expected to occur immediately within and adjacent to the Gatcombe and Golding Cutting Channels.

The estimated zones of impact for each stage of the campaign are provided in Appendix H.

It should be noted that the zones of impact in Figure 5-18 only relates to potential impacts from suspended sediment in the water column. Other impacting processes which may affect sensitive ecological receptors (such as sediment deposition and benthic habitat disturbance) are discussed further in the Project EIS Chapter 9 (nature conservation). The modelled impact to the 50th percentile deposition rate (Figure 5-16) is below the thresholds adopted for impacts to corals (Table 5-5).

Table 5-5 Preliminary matrix of impact zones for net sedimentation rate on corals

Zones	Sedimentation (mg/cm ² /day)
No impact	< 2.5mg/cm ² /day
Zone of influence and zone of low impact	< 2.5 to 10mg/cm ² /day
Zone of moderate impact	< 10 to 50mg/cm ² /day
Zone of high impact	> 50mg/cm ² /day

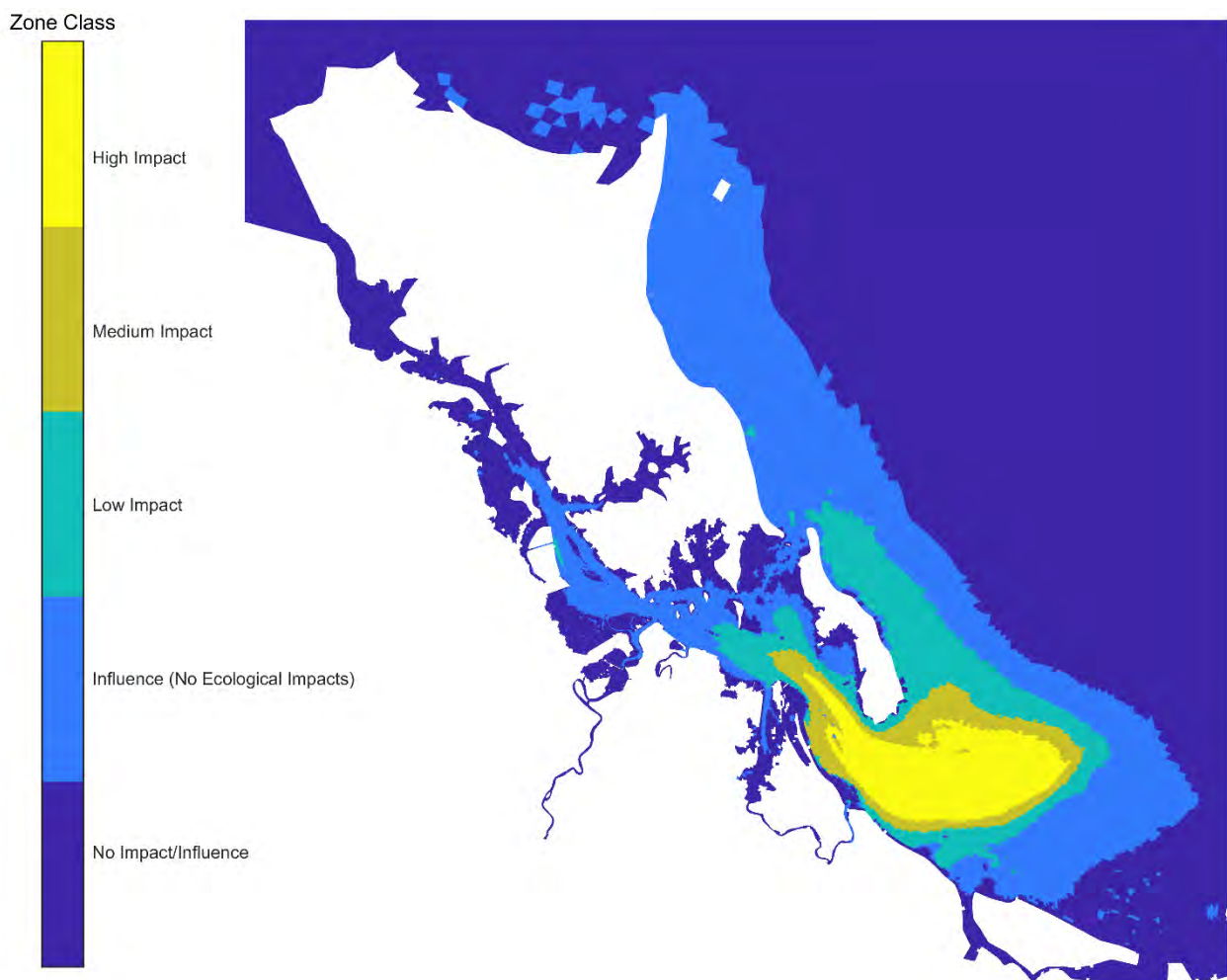


Figure 5-18 Zones of Impact for the Overall Capital Works Program

5.4.3 'Worst Case' Dredging Impacts

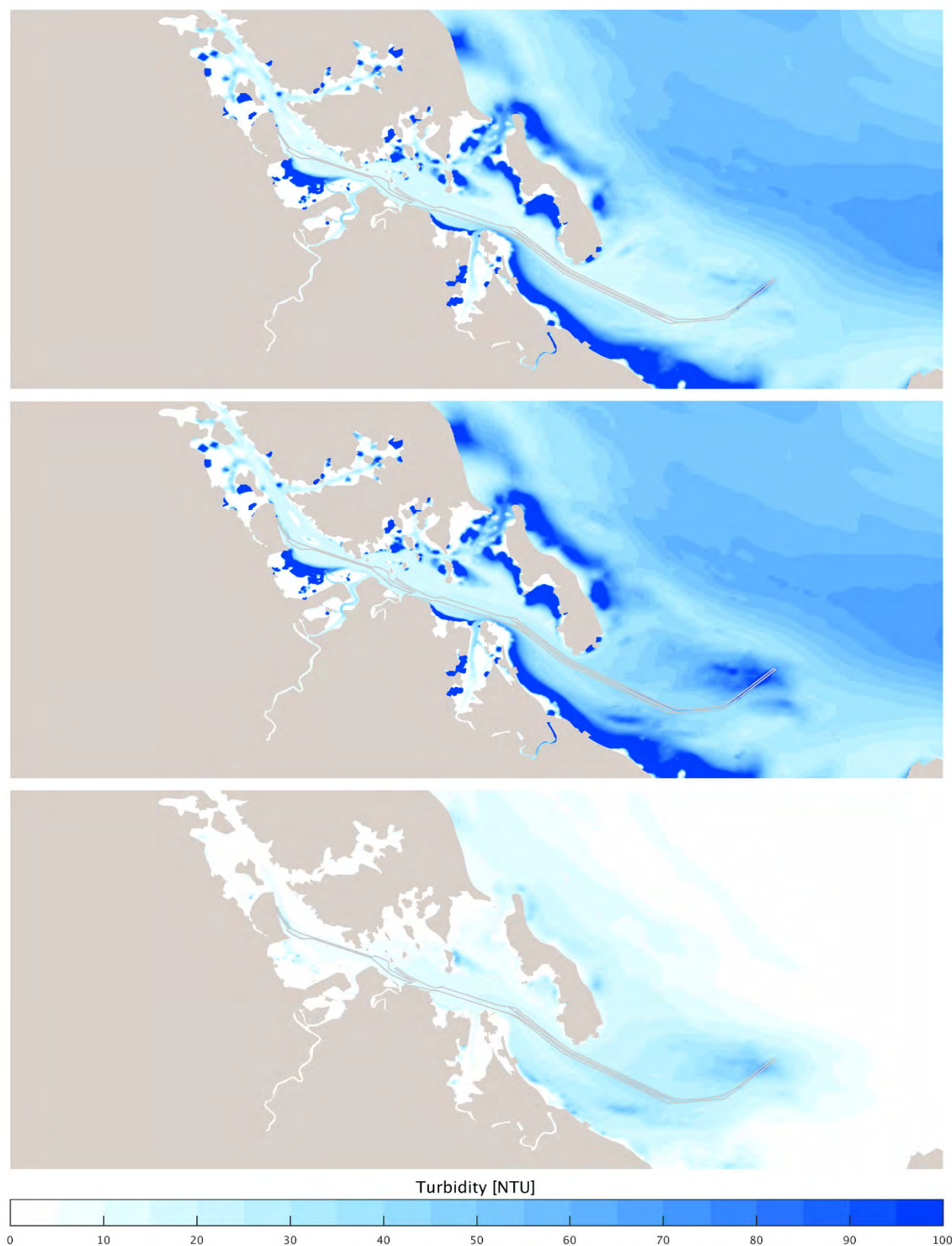
The 'worst case' assessment of potential impacts to turbidity and deposition rate was derived by calculating the highest modelled change in the turbidity and deposition rate percentiles over all of the 14-day assessment windows throughout the dredging campaign. Refer to Section 5.2.5 for details.

The top panel of Figure 5-19 shows the highest ambient (background) 95th percentile depth-averaged turbidity throughout the model domain over the 14-day simulation period. The middle panel shows the highest total (ambient plus dredging) 95th percentile turbidity throughout the model domain over the simulation period. The bottom panel shows the highest change in the 95th percentile turbidity due to the dredging activity over all of the 14-day windows during the campaign (indicating the impact to the turbidity level for 0.7 days out of the 14-day assessment window). The modelling results indicate a higher level of short term turbidity impacts in the outer parts of the shipping channel (than the results presented in Section 5.4.1) and in some areas within the Port due to high levels of resuspension of dredged sediment.

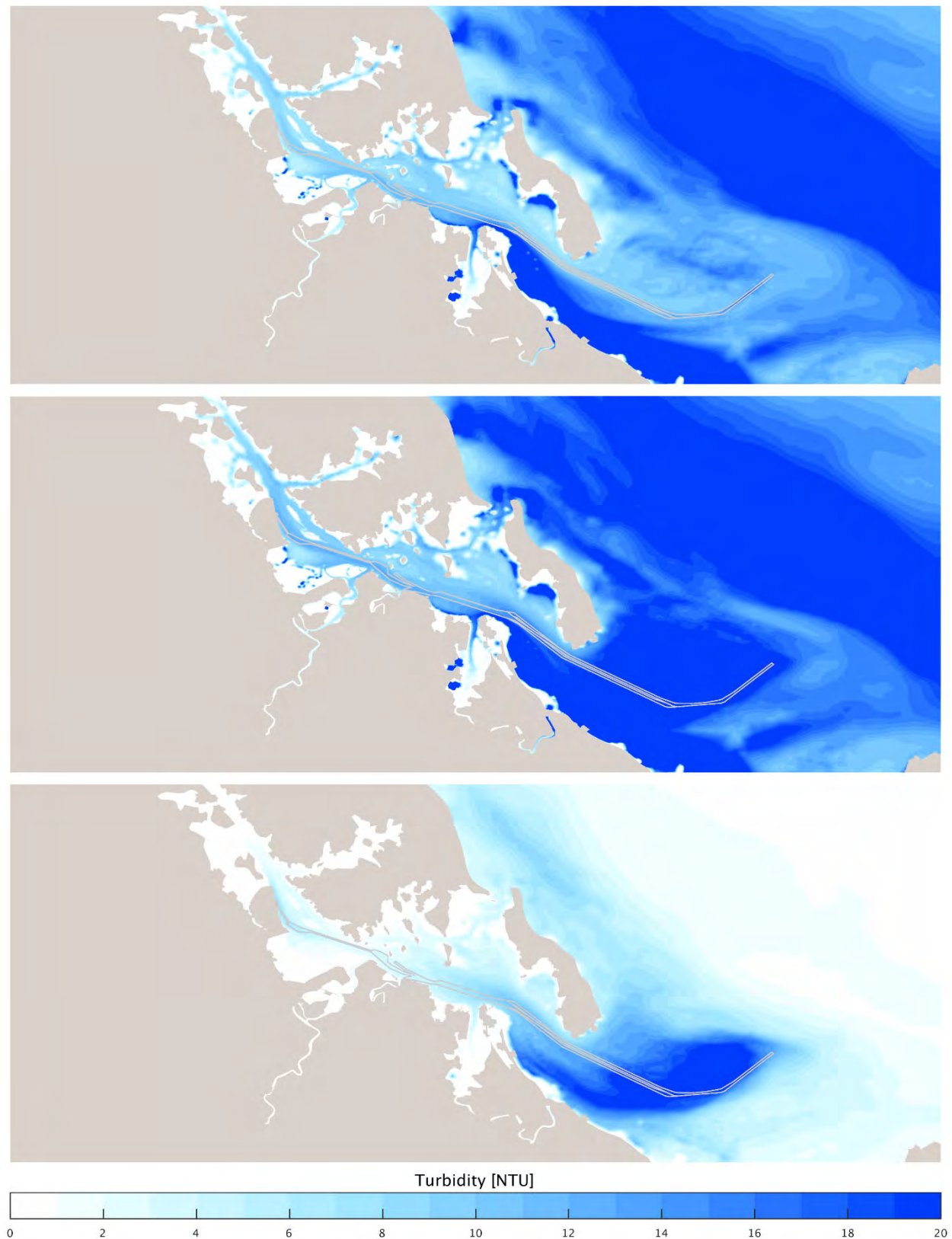
The top panel of Figure 5-20 shows the ambient 50th percentile depth-averaged turbidity throughout the model domain over the 14-day simulation period. The middle panel shows the total (ambient plus dredging) 50th percentile turbidity throughout the model domain over the simulation period. The bottom panel shows the highest change in the 50th percentile turbidity due to the dredging activity over all of the 14-day windows during the campaign (indicating the impact to the turbidity level for 7 days out of the 14-day assessment window). The modelling results indicate a higher sustained (but temporary) impact to turbidity levels in the vicinity of the dredging operation (relative to the results presented in Section 5.4.1).

The top panel of Figure 5-21 shows the ambient 95th percentile deposition rate throughout the model domain. The middle panel shows the total (ambient plus dredging) 95th percentile deposition rate throughout the model domain. The bottom panel shows the highest change in the 95th percentile deposition rate due to the dredging activity over all of the 14-day windows during the campaign (indicating the impact to the deposition rate for 0.7 days out of the 14-day assessment window). The modelling results indicate short term increases in the deposition rate in a number of areas within the Port and also along the coastline to the north.

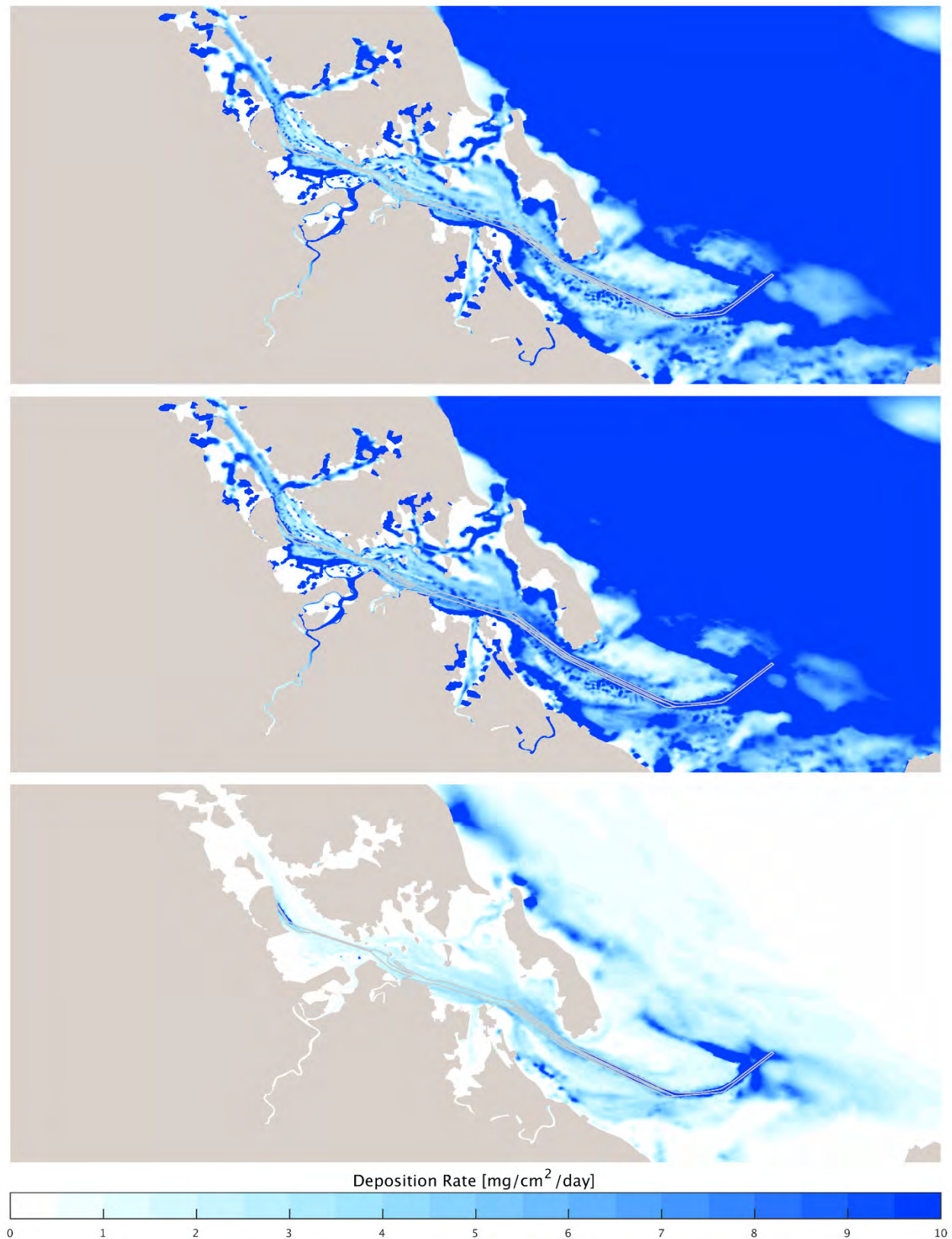
The top panel of Figure 5-22 shows the ambient 50th percentile deposition rate throughout the model domain. The middle panel shows the total (ambient plus dredging) 50th percentile deposition rate throughout the model domain. The bottom panel shows the highest change in the 50th percentile deposition rate due to the dredging activity over all of the 14-day windows during the campaign (indicating the impact to the deposition rate for 7 days out of the 14-day assessment window). Some minor sustained (but temporary) increases in the deposition rate are noted within the Port.



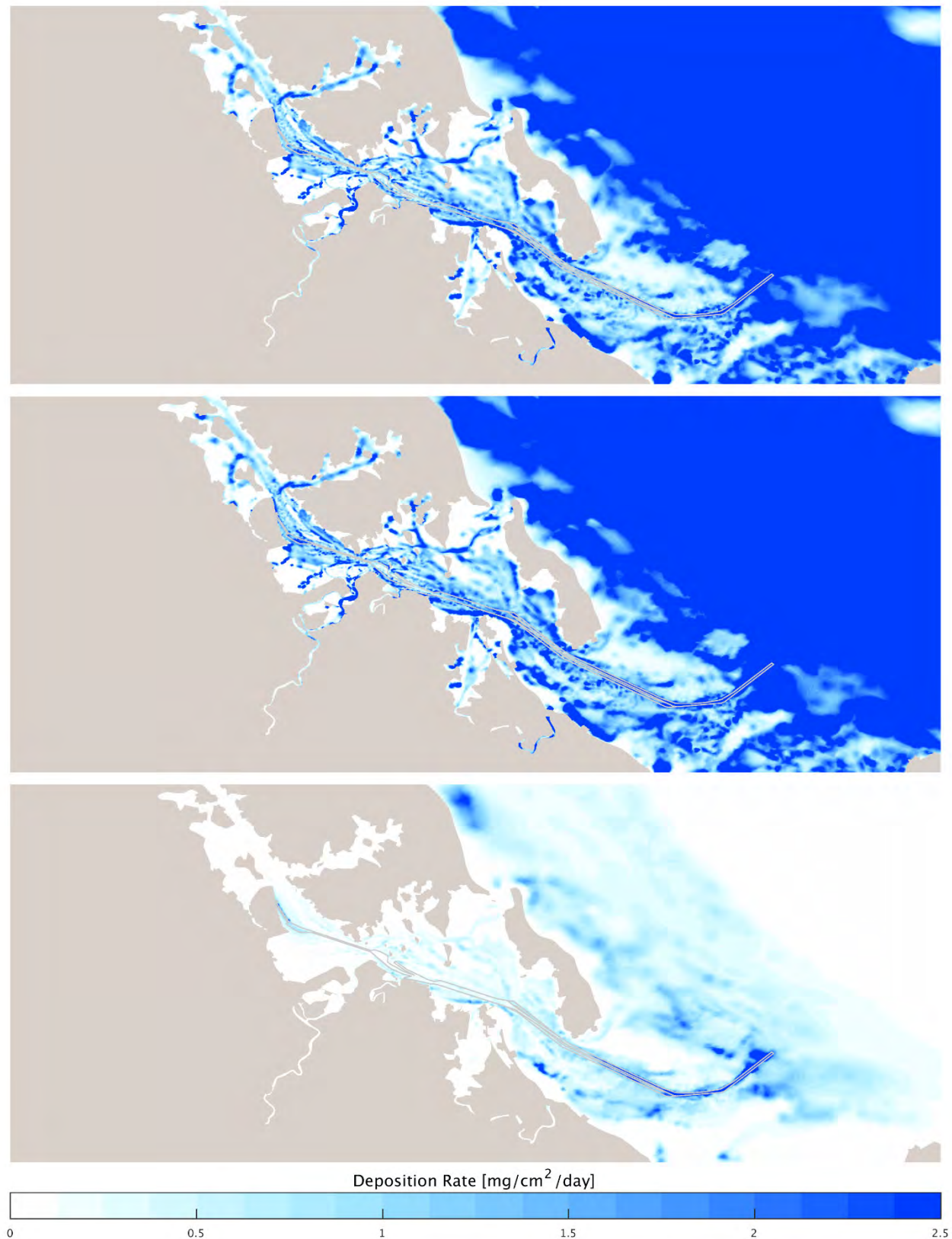
**Figure 5-19 95th Percentile of the Depth Averaged Turbidity
 Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
 'Worst Case'**



**Figure 5-20 50th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
'Worst Case'**



**Figure 5-21 95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
'Worst Case'**



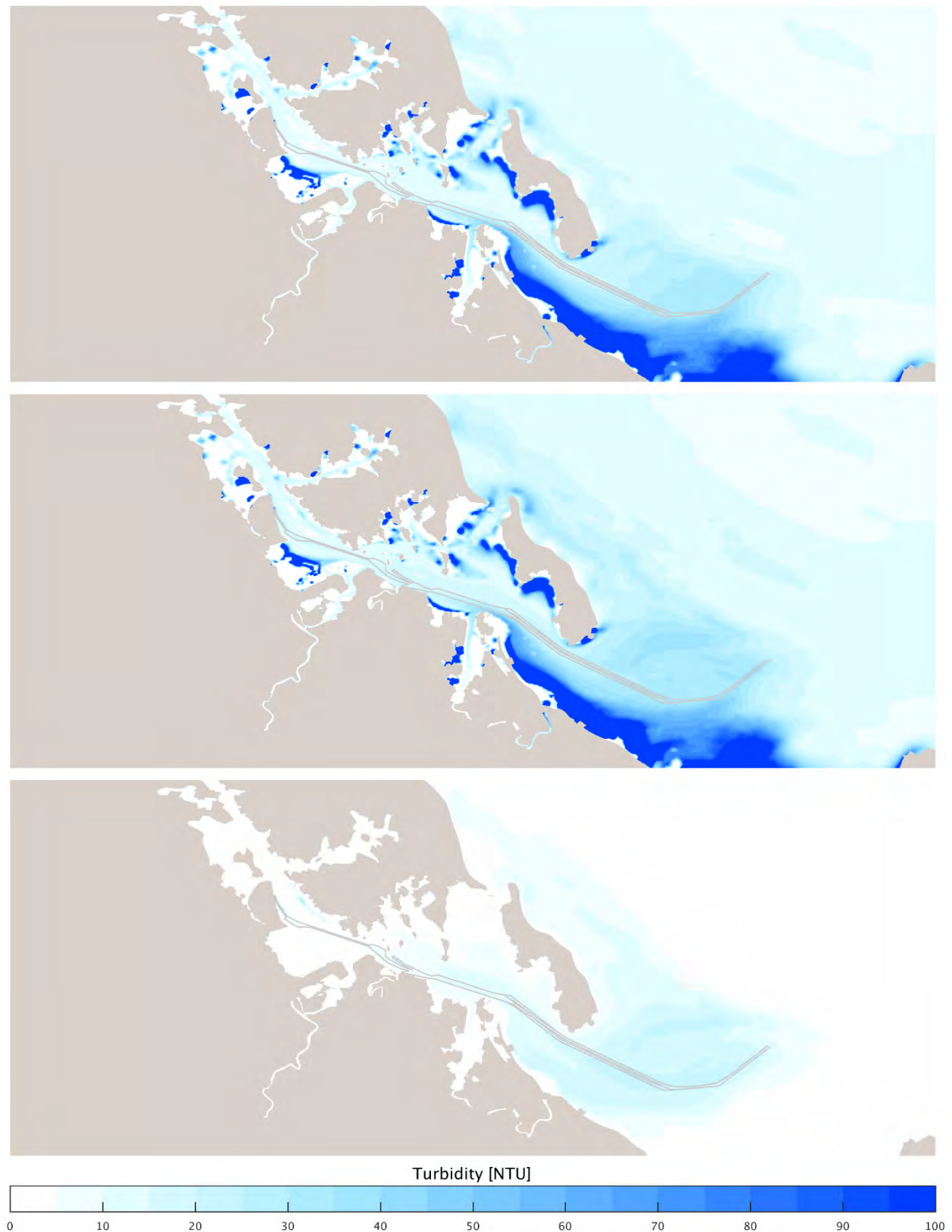
**Figure 5-22 50th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
'Worst Case'**

5.4.4 'Cumulative Case' Assessment

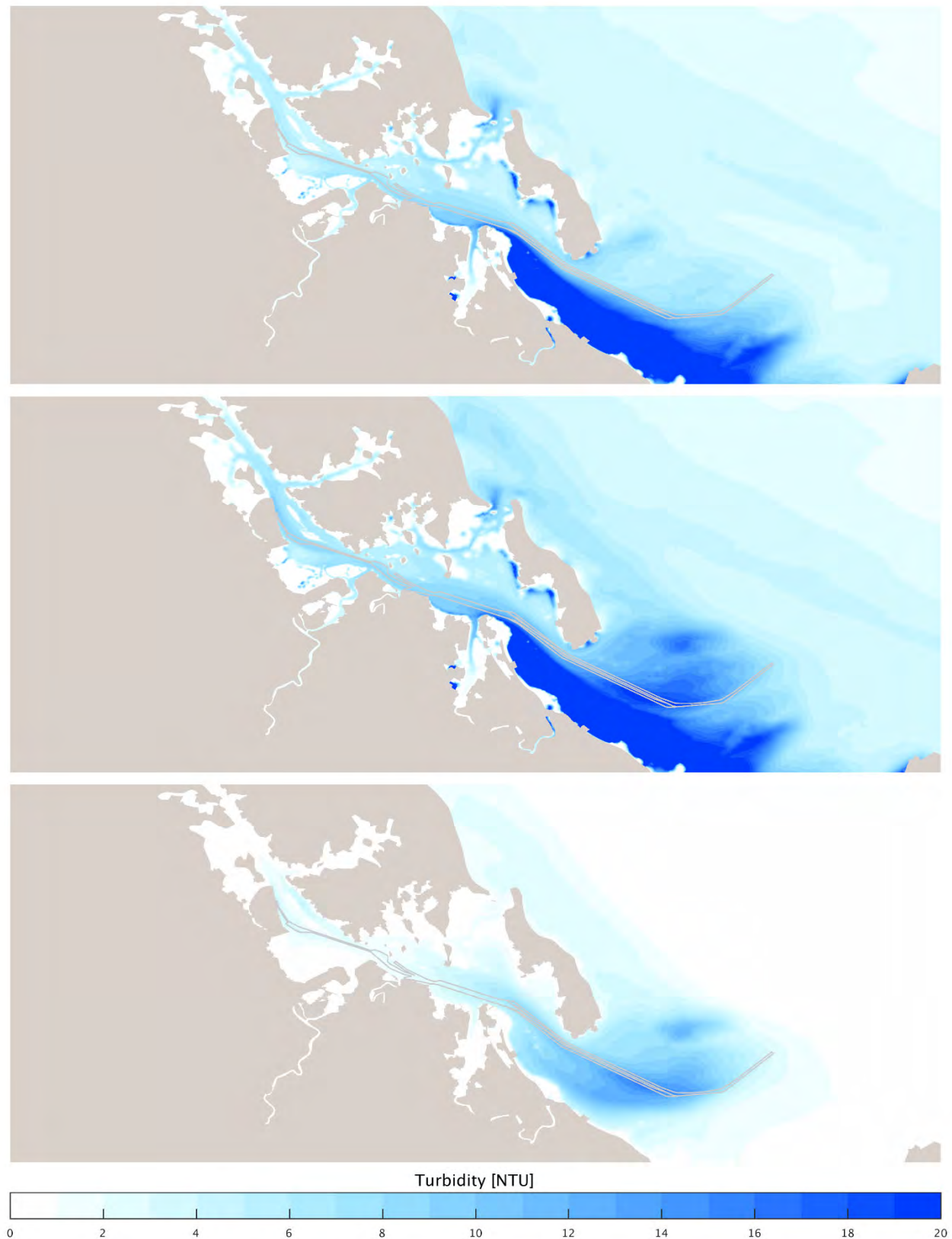
5.4.4.1 Maintenance Dredging

The overall impact on turbidity percentiles for the maintenance dredging cumulative case (combining the capital dredging campaign with a Port-wide maintenance dredging campaign (i.e. 260,000m³) which represents the typical annual dredged material volume) is presented in Figure 5-23 for the 95th percentile (short term) impacts and Figure 5-24 for the 50th percentile (sustained) impacts. The modelled impacts to the turbidity percentiles are slightly higher than the 'capital dredging only' case (Section 5.4.1), particularly near the offshore East Banks dredged material placement area (DMPA).

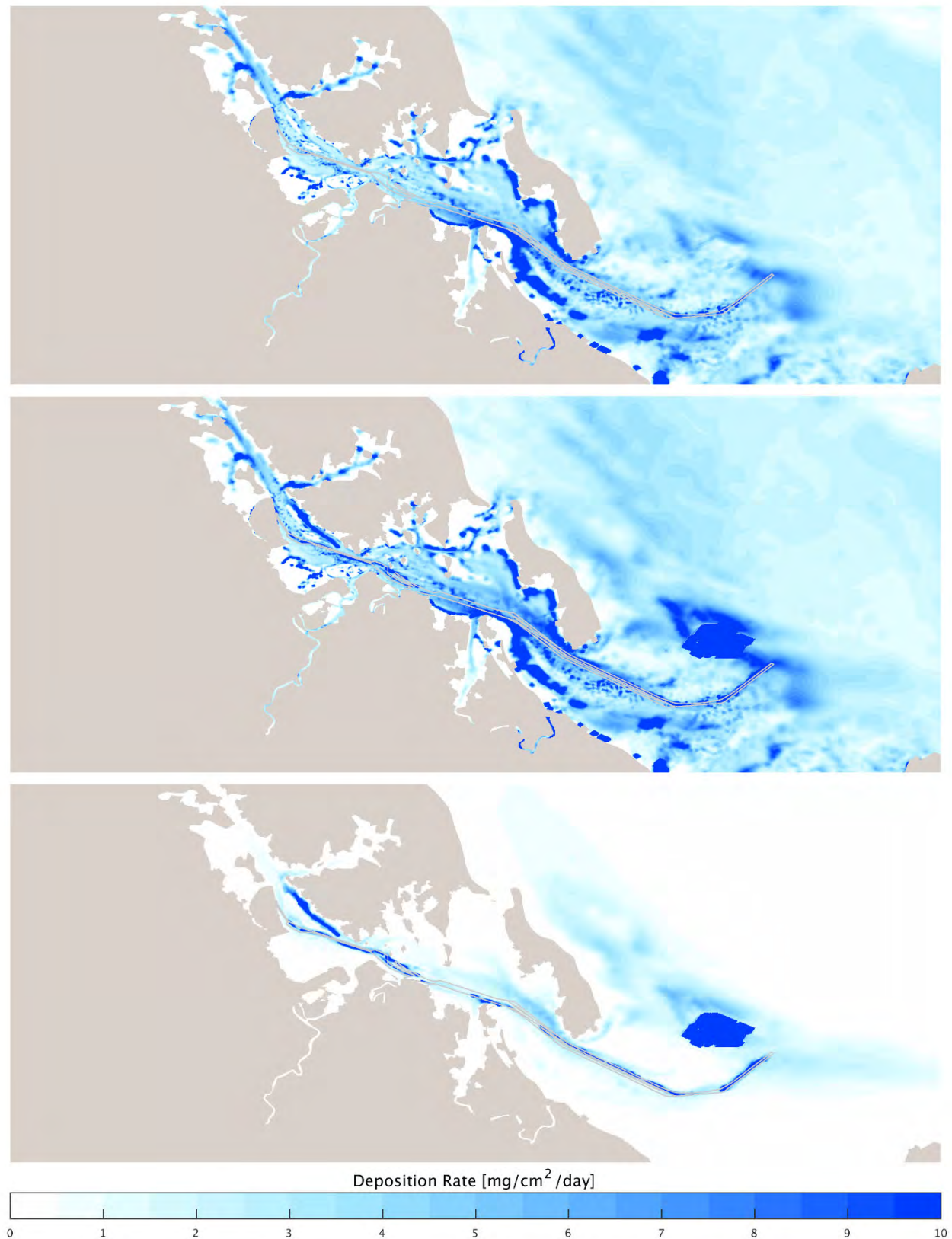
The analysis of the deposition rate percentiles for the maintenance dredging cumulative case (combining the capital dredging campaign with a Port-wide maintenance dredging campaign (i.e. 260,000m³)) is presented in Figure 5-25 for the 95th percentile (short term) impacts and Figure 5-26 for the 50th percentile (sustained) impacts. The modelled short term impact to the deposition rate is higher than the 'capital dredging only' case (Section 5.4.1) at the offshore East Banks DMPA (maintenance dredged material only), in the vicinity of the WBE reclamation area and in certain areas within the estuary. The sustained (but temporary) impact to the deposition rate is higher than the 'capital dredging only' case in offshore areas (due to resuspension from the East Banks DMPA) and in the Jacobs Channel area adjacent to Curtis Island.



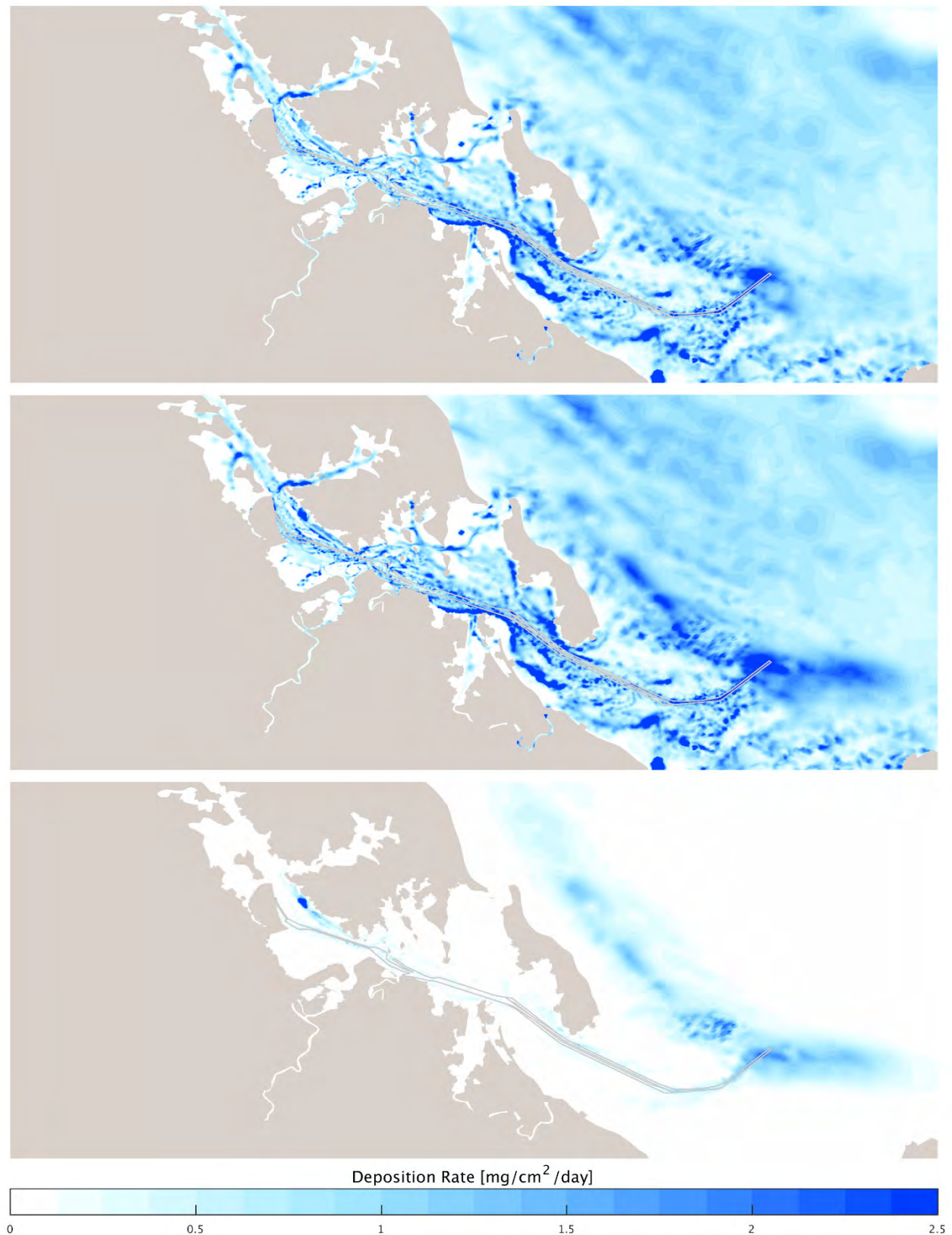
**Figure 5-23 95th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Maintenance Dredging Cumulative Case**



**Figure 5-24 50th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Maintenance Dredging Cumulative Case**



**Figure 5-25 95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Maintenance Dredging Cumulative Case**

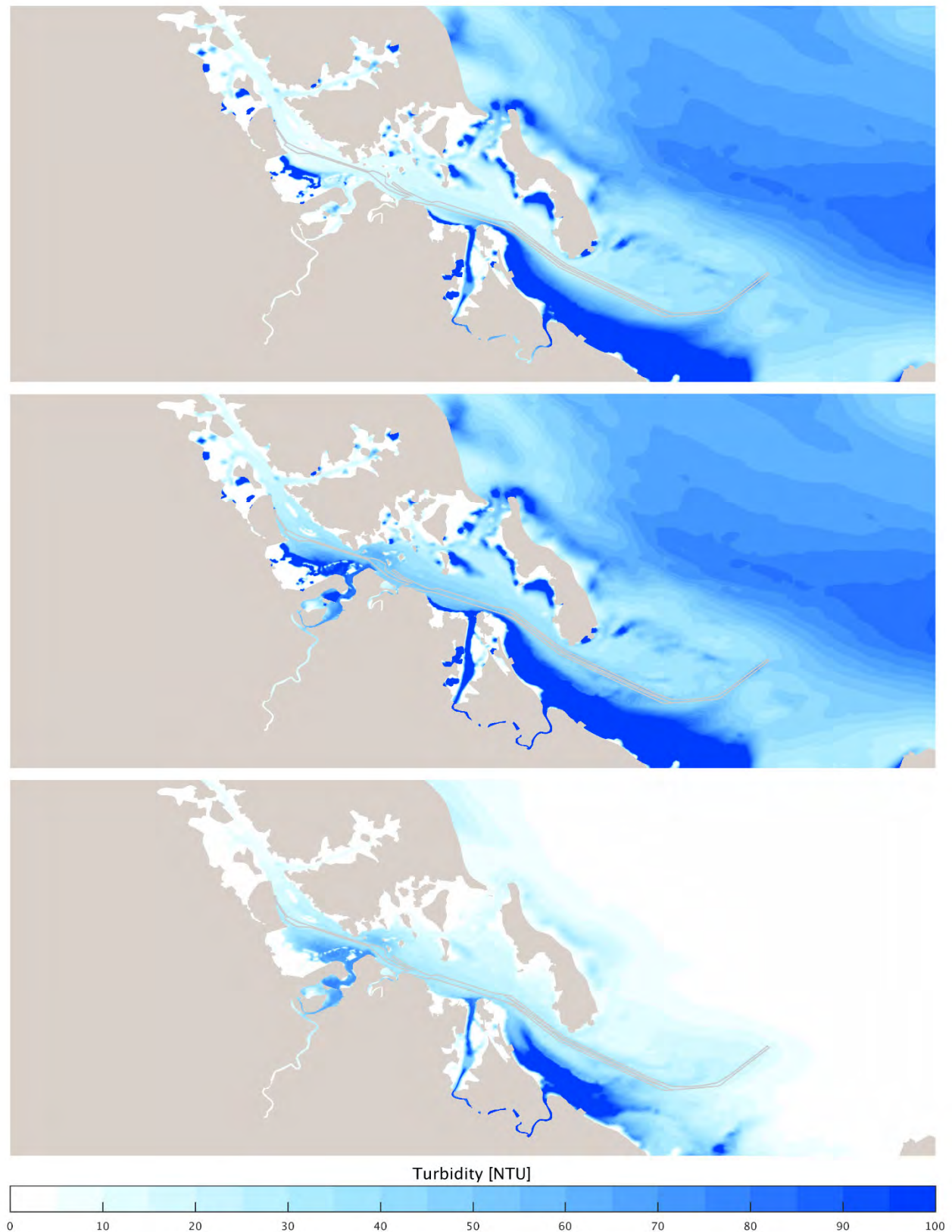


**Figure 5-26 50th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Maintenance Dredging Cumulative Case**

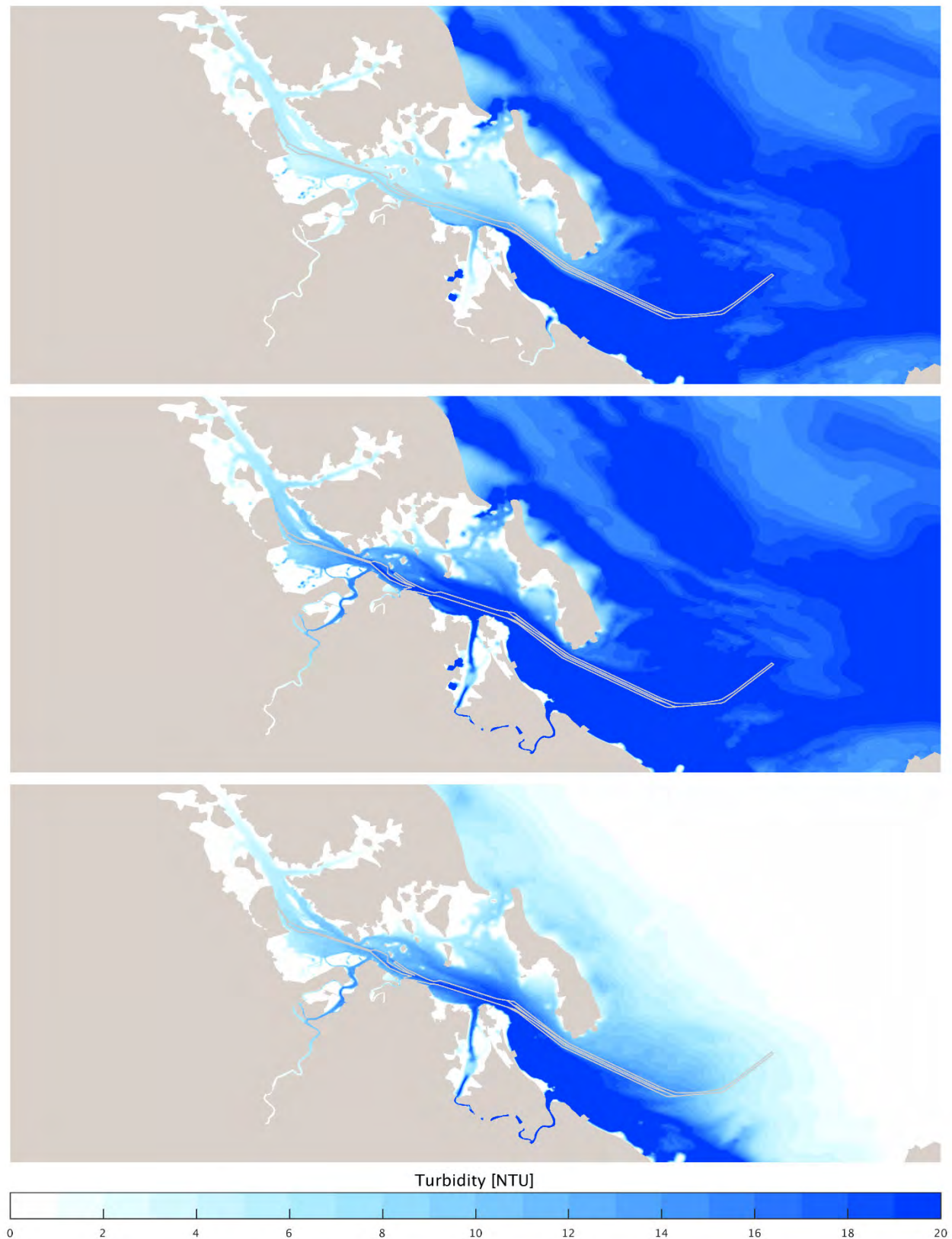
5.4.4.2 Flood Event

The overall impact on turbidity percentiles for the flood cumulative case (combining Stage 1 of the Project capital dredging campaign and the 2013 flood event) is presented in Figure 5-27 (95th percentile, short term impacts) and Figure 5-28 (50th percentile, sustained impacts). The modelled impacts to the turbidity percentiles are higher than the 'capital dredging only' case (refer Section 5.4.1) within and adjacent to the entrances of the Calliope and Boyne Rivers, due to the influence of flood-related plumes.

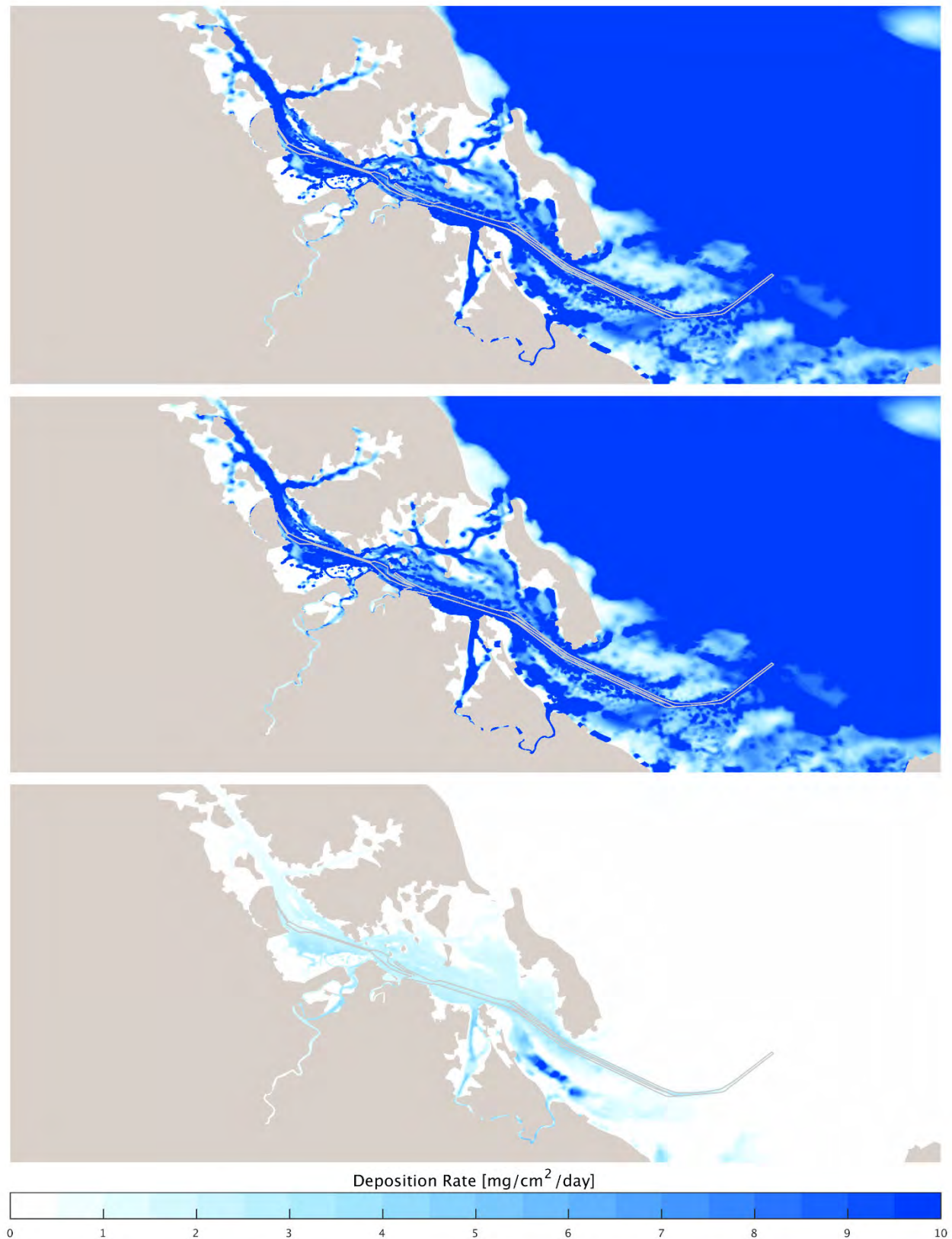
The overall impact on deposition rate percentiles for the flood cumulative case (combining the capital dredging campaign with the 2013 flood event) is presented in Figure 5-29 (95th percentile, short term impacts) and Figure 5-30 (50th percentile, sustained impacts). The modelled impacts to deposition rate are higher than the 'capital dredging only' case (refer Section 5.4.1) within several areas dispersed throughout the estuary.



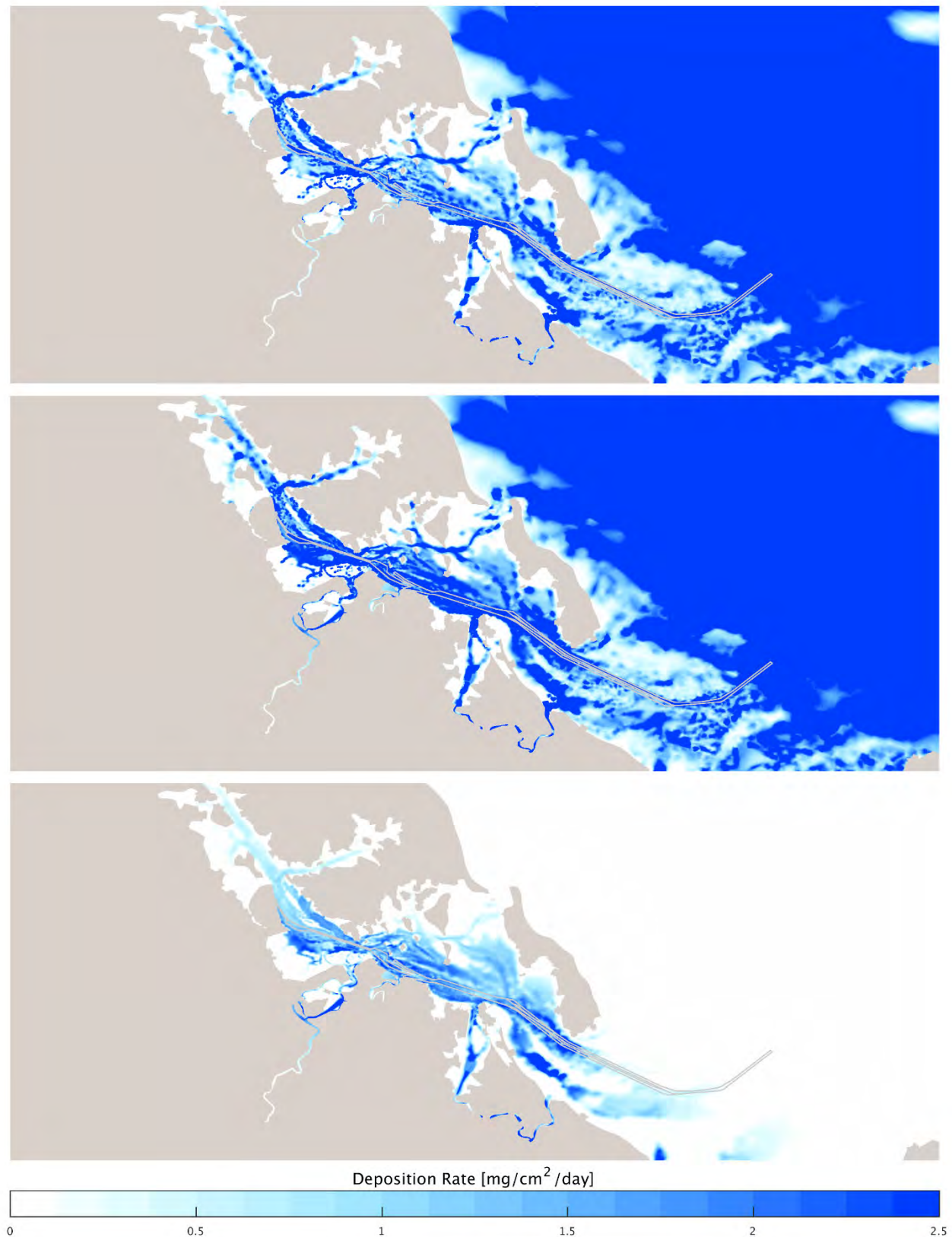
**Figure 5-27 95th Percentile of the Depth Averaged Turbidity
 Ambient (Top), Total (Middle) and Impact of Flood and Dredging (Bottom)
 Flood Event Cumulative Case**



**Figure 5-28 50th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Flood and Dredging (Bottom)
Flood Event Cumulative Case**



**Figure 5-29 95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Flood and Dredging (Bottom)
Flood Event Cumulative Case**



**Figure 5-30 50th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Flood and Dredging (Bottom)
Flood Event Cumulative Case**

5.4.5 Tailwater Plume Dispersion

Although the discharge of tailwater discharge was included in all of the modelling results presented in the previous sections, an additional simulation of the tailwater discharge was carried out to illustrate the rapid mixing and dispersion of the plume in typical tidal conditions. The model snapshots shown in Figure 5-31 illustrate that even during neap tides, when tailwater plume concentration would be highest, the modelled depth-averaged tailwater-related TSS concentration is very low (less than 2 mg/L). The channel between the reclamation areas has very good tidal flushing characteristics.



Figure 5-31 Typical Tailwater Plume Depth-Average TSS Concentration (Top: Neap Flood Tide, Bottom: Neap Ebb Tide)

6 Conclusion

6.1 Model Development and Calibration

Numerical modelling was used to inform the environmental assessments for this Project. Section 2 of this report describes the methodology, boundary conditions, data collection and calibration of the numerical models used in the environmental impact assessment process. The modelling was undertaken in accordance with the GBRMPA Modelling Guidelines (GBRMPA, 2012) and the validation results indicate that the models are able to replicate the key physical processes in the Port Curtis estuary with sufficient accuracy.

6.2 Existing Coastal Processes and Hydrodynamics

The key features of the existing coastal processes and hydrodynamics in Port Curtis are described in Section 3 of this report. Port Curtis has good tidal flushing characteristics and spring tidal velocities are generally high (up to 2 m/s). Waves are important drivers of sediment dynamics both within the estuary and in offshore areas. Within the Port, the bed shear stress associated with the tidal currents is generally the dominant driver of sediment resuspension and wave-related bed shear stress is of secondary importance. In the outer reaches of the Port, and in offshore areas, wave energy is higher and tidal velocities are lower and therefore the wave-related bed shear stress is a much more significant driver of resuspension processes overall. Shoreline coastal processes within the study area are influenced by the local wave climate as well as the tidal hydrodynamics and sediment dynamics.

6.3 Impact Assessment

Section 4 of this report describes potential impacts to hydrodynamics and coastal processes associated with the Project. The modelling results indicate that water level impacts will be negligible. Velocity impacts will be significant in channels adjacent to the WBE reclamation area, but small in the vicinity of the deepened shipping channels. Wave climate impacts will be limited to the immediate vicinity of the WBE reclamation area. Sedimentation and erosion impacts will be most significant adjacent to the WBE reclamation area, but there will also be a slight increase in overall Port-wide annual maintenance dredging requirements. The deepening of the shipping channels will not cause any change to the projected impacts of climate change and SLR in the Project area.

6.4 Modelling of Dredging Activities

The modelling of the dredging activities and associated suspended sediment plumes is described in Section 5 of this report. The model was used to simulate the full dredging program and the expected impacts to the turbidity percentiles and deposition rates due to dredging were assessed. The model results indicate that increases to the turbidity and deposition rate statistics are expected near the WBE reclamation area and in the vicinity of the TSHD operating in the Gatcombe and Golding Cutting bypass channels. The zones of impact and influence associated with suspended sediment plumes were derived and discussed, and are further interpreted in the nature conservation and water quality chapters of the EIS.

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Appendix A GBRMPA Hydrodynamic Modelling Guidelines

The use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park

August 2012

To provide guidance on the use of three-dimensional (3D) hydrodynamic numerical models in the Great Barrier Reef Marine Park. Deviations from these guidelines require prior written approval from GBRMPA.

General Principles

1. These guidelines, prepared by the Great Barrier Reef Marine Park Authority (GBRMPA), are used to inform proponents and interested stakeholders about the specific procedures, methodologies and frameworks associated with hydrodynamic modelling and dredge plume modelling that GBRMPA expects for projects in the Great Barrier Reef Marine Park (Marine Park).
2. Three-dimensional (3D) hydrodynamic numerical modelling of sediment plumes underpins the assessment of potential impacts from dredging and sediment disposal activities in the Marine Park.
3. Actions to avoid, mitigate, and/or offset and adaptively manage potential impacts from dredging and disposal activities will be based on the model outputs.
4. Modelling is used to predict the extent, intensity and persistence of dredge-generated sediment plumes and the extent, severity and duration of resultant indirect impacts to benthic habitats, which can range in severity and duration from irreversible to readily reversible.
5. The use of 3D hydrodynamic and sediment plume modelling is considered international best practice.
6. The hydrodynamic model should take into account the tides, the wind, the waves and the mean prevailing circulation (oceanic currents) and potential stratification from river discharges.
7. The model must be calibrated and validated against collected baseline information.
8. 3D modelling must include all types of potential re-suspension including current and wave-induced bottom shear stress and wave-induced mud fluidization.
9. GBRMPA supports the use of the Western Australia's Environmental Protection Authority 'Environmental Assessment Guideline for Marine Dredging Proposals'¹ and the use of a zonation scheme in describing impact predictions (i.e. zone of impact, zone of influence).

Baseline information

10. For dredging campaigns less than one month duration, a minimum of one month of baseline data collection is required. For wind data collection, 3 to 4 months of baseline data is required.



11. For dredging campaigns that are predicted to last longer than one month, then a minimum of twice the duration of the dredging campaign worth of baseline data is required to account for seasonal variation. For example, if the dredging campaign is 2 months, then at least 4 months of baseline data is required. For wind data collection, six to eight months of baseline data is required.
12. Baseline data must be measured in close proximity to the dredging and disposal sites and include metocean parameters such as tidal range, wave height, water current, wind direction and intensity and sediment dynamics.

Sediment transport

13. Sediment transport modelling must consider the a range of particle sizes. The size of the particle will determine its behaviour in the marine environment and thus how it is numerically modelled. For example:
 - a. Sand is generally modelled as bed load;
 - b. Silt is modelled using a fixed settling velocity. Due to the range of silt fractions a silt particle may behave similar to a sand particle or a mud particle;
 - c. Mud (clay) is modelled with a settling velocity which is determined as a function of the suspended sediment concentration in order to take into account the process of flocculation.

Model resolution

14. Predictive modelling of dredge plumes must:
 - a. Describe whether the model uses a z or σ coordinate in the mesh.
 - b. Adequately resolve how the model deals with sudden changes in bathymetry. For example: a dredge channel or coral reef as percentage error in the prediction.
 - c. It is recommended that the minimum resolution as a function of mesh size to pick up changes in hydrodynamic flow associated with a dredge channel is two cells within the width of a dredged channel.

- d. Describe the physical characteristics of the sediment being transported. These characteristics should be informed by sampling undertaken in accordance with the *National Assessment of Guidelines for Dredging 2009* (NAGD).
- e. Accurately represent the ambient conditions at the time of year in which the dredging occurs. If this is not known, then modelling should be undertaken for all seasons (i.e. summer conditions, winter conditions, transitional conditions) using the corresponding prevalent oceanographic conditions.
- f. Include additional dispersion and re-suspension from both dredging operations and dredge disposal activities. This must be completed for a range of probable hydrodynamic conditions, weather events and expected dredge equipment scenarios. The amount of material liberated by the dredging and dispersed in the environment around the dredge site must also be stated.
- g. Numerical modelling must be performed for a duration of time that is long enough to establish the re-suspension associated with different weather conditions that occurs after dumping and initial settling.
- h. If dredging is to occur near coral sand islands, modelling of particles must be undertaken using coralline sand characteristics. The use of sand particles in this scenario is not supported.

Model outputs

15. GBRMPA expects that direct, indirect and sublethal impacts of sediment plumes are considered.
16. Numerical models must use a spatially based scheme that provides for a clear and consistent way of describing and presenting the extent, severity and duration of predicted impacts of dredging and dredge disposal and must include likely "best case" and likely "worst case" scenarios.

17. The lethal and sublethal thresholds used for the ecological response modelling must be clearly indicated and supported by peer reviewed scientific published papers and compared against model outputs.
18. The output from the model should be overlaid upon maps of the sensitive habitats and ecological receptors in order to visualise and interpret what the impact of the sediment plume might be.
19. GBRMPA expects all modelling results (maps) to be provided in a suitable GIS compatible format (i.e. shapefiles in geographic coordinates and GDA94 datum) to GBRMPA.
20. Outputs should at a minimum requirement include maps showing the predicted maximum suspended solid concentration at mid-depth and near the seafloor, the predicted median suspended solid concentration at mid-depth and near the seafloor, and the predicted sedimentation rate (g/cm^2) over the duration of the project, as well as time-series predictions of these three parameters at key sites over the duration of the project.
21. GBRMPA encourages consistency when using sediment loading units (NTU's, mg/L or kg/m^3). Do not use the units interchangeably.
22. Selection of dredge disposal site (even if a historic site) must be fully justified and compared to other possible sites with a prediction for sediment re-suspension and possible direction and distance of the migration of the dredge material under different water current conditions.
23. If GBRMPA is uncertain about the methodology used in the modeling, then the methodology and the model outputs will be independently peer reviewed at the cost of the proponent.

Background

Justification

1. The Great Barrier Reef Marine Park (Marine Park) is widely recognised as one of the best managed marine areas in the world. It is a multiple-use Marine Park that supports a range of activities, industries, communities and businesses. However, it faces challenges from a range of threats including climate change, declining water quality, increased coastal development and the growth in ports and shipping activities.
2. The economy of Queensland continues to grow and some industries are developing rapidly, such as coal and mining, which is fuelling growth in ports in the Great Barrier Reef Region and increasing the number of ships travelling through Reef waters. This growth results in the construction of new shipping berths, dredging of shipping channels and the dumping of dredge material. All of these have the potential to impact on the marine environment.
3. The Great Barrier Reef Marine Park Authority (GBRMPA) is committed to protecting the Great Barrier Reef from the impacts of ports and shipping on the Marine Park through a range of management initiatives and partnerships with other government agencies.
4. Numerical models are used to quantify the predicted impact of dredging and disposal on marine ecosystems. The hydrodynamic model predicts the physics of water, sediment dynamics and oceanographic behaviour.
5. The Guidelines provide for a transparent and acceptable standard to assist in the development of predictive numerical models associated with dredge related sediment plumes in and adjacent to the Marine Park. They allow for the understanding of the fate of suspended sediments within the marine environment and potential for impacts to sensitive marine receptors.

Background

6. Dredging activities can have adverse effects on marine ecosystem (see figure 1). Dredging and dredge disposal at sea can result in environmental impacts such as:
 - a. Increased concentrations of suspended sediments²
 - b. Changes to hydrodynamics
 - c. Smothering of benthic fauna and flora
 - d. Introduction of contaminants
 - e. Alteration of coastal processes
 - f. Damage to marine wildlife
 - g. Translocation of pest species
 - h. Removal of habitat.

Increased concentrations of suspended sediments

7. Dredging involves the removal of sediments from the seafloor. This disturbance creates sediment plumes, which decreases water clarity and quality. The plume reduces light penetration to the seafloor; it affects fish behaviour and other benthic life³. Coarser-grain sediments such as sands will sink to the substrate quickly, but finer-grain sediments such as silt and clay will remain suspended in the water column for an extended period of time⁴ because of the low settling velocity⁵.

8. Sediment plumes can also liberate nutrients⁶ and once the nutrients are dispersed into neighbouring areas by the effect of currents and waves, they have the potential to be detrimental to the surrounding marine life⁷. Sediments, once settled, can adversely affect the seagrasses, bottom-dwelling organisms and their eggs through smothering and burial⁸.
9. The reduction in light also prevents pelagic and benthic organisms from seeing and sensing their food, preys, predators, mates and offspring. Suspended sediments can clog fish gills and reduce their resistance to disease⁹.

Changes to Hydrodynamics

10. The creation of an artificial channel and reclamation of the seafloor causes a change in hydrodynamics which in turn causes turbulent flow. The water circulation pattern changes once currents are influenced by the structures. It is therefore imperative that 3D turbulent flow over the structures must be considered in the model in order to ascertain the momentum and intensity of the turbidity currents.

Smothering of benthic fauna and flora

11. The increase in turbidity can retard the growth of flora and fauna. It also suffocates the newly hatched larvae. The resettled sediments can cover the spaces between the rocks thus displacing the habitats of bottom-dwelling organisms¹⁰.

3D Hydrodynamic Model as Best Practice

12. Hydrodynamic models are generated by computer softwares. A two-dimensional hydrodynamic model, though useful in many situations, is limited to its depth-averaged equations and thereby unable to resolve stratification or vertical gradients¹¹. However, a three-dimensional model, though complex but made easy by the power of modern computers, can determine the vertical distribution of currents.¹² It provides the most complete solution for any hydrodynamic system¹³ including the formulation for the effects of bottom shear stress and surface wind shear stress¹⁴. A 3D hydrodynamic model is highly recommended as best practice because it provides realistic simulation of the marine environment.
13. The World Heritage Report on the Great Barrier Reef highlighted that any developments or associated activities are to be carried out with the highest international standards of best practice commensurate with status of an iconic World Heritage Property¹⁵.

Legislation governing dredging and dredge disposal

14. International protocols and Commonwealth legislation requires the protection and preservation of the marine environment from pollution related to spoil disposal at sea. The *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972*, which Australia is a party to, recognises ocean disposal as the least favoured method of dredge material disposal. The *Environment Protection (Sea Dumping) Act 1981* is the domestic legislation through which Australia regulates sea dumping and meets its international obligations under the protocol.
15. Dredge disposal in the Marine Park or in the World Heritage Area is subject to rigorous environmental assessment. Dumping in the Marine Park requires a permit under the *Great Barrier Reef Marine Park Act 1975*; and dumping in the World Heritage Area requires consideration against the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and approval under the *Environment Protection (Sea Dumping) Act 1981*.
16. For loading or dumping within the Marine Park, GBRMPA holds the delegation for the assessment and granting of Sea Dumping permits under the Sea Dumping Act, notwithstanding that one or more of the activities associated with the dumping, such as dredging, may occur outside the Marine Park.

17. Most ports are located outside the Marine Park, but are within the World Heritage Area. This means that the majority of a port's activities are outside of GBRMPA's direct jurisdiction and are mostly managed by the Federal Department of Sustainability, Environment, Water, Population and Communities.
18. The *Great Barrier Reef Marine Park Act 1975 (Marine Park Act 1975)*
 - 18.1. The main object of the Marine Park Act 1975 is to provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region.
 - 18.2. Regulations may be made under the Marine Park Act 1975 to regulate or prohibit activities in the Marine Park (Section 66).
 - 18.3. Under section 38AA of the Marine Park Act 1975, it is an offence to carry out an operation for the recovery of minerals in the Marine Park, which may include some dredging operations. There is also the *Great Barrier Reef Region (Prohibition of Mining) Regulations 1999* which was gazetted on the 23 December 1999. These regulations identify 'mining operations' which include 'operations for the recovery of minerals' as a prohibited activity in the Great Barrier Reef Region, adjoining the Marine Park.
19. The *Great Barrier Reef Marine Park Regulations 1983*

In deciding whether or not to grant an application, GBRMPA must consider matters outlined in Regulation 88Q (mandatory considerations) and may consider matters outlined in Regulation 88R (discretionary considerations). Mandatory considerations include: the potential impacts of the proposal on the environment and on the social, cultural and heritage values of the Marine Park; options for monitoring, managing and mitigating the potential impacts; the objectives of the Great Barrier Reef Marine Park zone in which the proposal will take place; whether the proposal requires an approval under the EPBC Act; written submissions from the public about the proposal; and matters relevant to the proper and orderly management of the Marine Park.
20. The *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*
 - 20.1. On 25 November 2009, legislative changes came into effect to better integrate the Marine Park Act 1975 with the national environment law – the EPBC Act, so that a single environmental impact assessment system applies to development proposals in the Marine Park. If a development proposal is referred under the EPBC Act, and the action or a component of that action requires a permission under the Marine Park Act 1975, the EPBC Act referral is deemed to be a Marine Park application.
 - 20.2. The legislative changes also established the Marine Park as a 'matter of national environmental significance' (known as a NES matter) under the EPBC Act. This means that development proposals outside the Marine Park that are likely to have a significant impact on the environment of the Marine Park, or other NES matters, must be assessed under the EPBC Act.

Relationship to other GBRMPA Policies or Position Statements

21. This Policy relates to the following GBRMPA Policies and Position Statements at the time of review:
 - 21.1. **Environmental Impact Management Policy** - sets the framework for assessment, mitigation and management of environmental impacts associated with development activities in the Marine Park and World Heritage Area.
 - 21.2. **Dredging and Spoil Disposal Policy** - sets out the guidelines as to what is to be done with contaminated dredge material, where to dispose the dredge material in the Marine Park, the limitation of maintenance dredging volume and the environmentally levy that may be charged.
 - 21.3. **Ports and Shipping Information Sheet** – describes the current dredging activities and the proposed port expansion in the Marine Park and World Heritage Area. Facts and figures are listed to show the magnitude of dredging and port expansion.

Definitions

22. *Dredge Disposal*

The relocation of dredge material from the dredging site to a designated disposal site. Disposal sites may include marine or land based receiving facilities.

23. *Wave-induced Bottom Shear Stress*

A wave-induced bottom shear stress is a stress that is generated by ocean waves as they propagate over the sea floor. It is an important parameter for understanding sediment dynamics and bottom properties¹⁶ and for calculating erosion, storm surge, wave height attenuation and coastal structural stability¹⁷. In coastal zones where the ocean depths are shallower than 4 m, the bottom shear stresses are greater¹⁸.

24. *Mud Fluidisation*

Mud fluidisation is a process or condition in which the contact stresses between particles in the mud reduce to zero. The mud is thus converted from a solid-like state to a dynamic fluid-like state as the granular material loses its shear strength¹⁹. This process occurs as the fluid passes through mud particles. The waves could fluidise the mud, but they do not transport the sediment. As soon as the mud has been fluidised, the currents erode it away²⁰.

25. *Flocculation*

Flocculation is the process of sediments forming naturally or by the addition of flocculants larger aggregates, agglomeration or clusters of sediment particles.

GREAT Barrier Reef Marine Park Authority (GBRMPA) Decision(s)

Approved by:	General Manager, Marine Park Management Branch, Great Barrier Reef Marine Park Authority 14 August 2012
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Appendix B Data Collection Program and Correspondence from GBRMPA

Memorandum

To	Kevin Edison (GBRMPA) Tim Ipkendanz (DotE) Steve Elson (DEHP)	From	Stephen Cole
Copy	Anthony Mines (Office of CG) Anil Bhakta (GPC)	Reference	237374
Date	30 May 2014	Pages (including this page)	3
Subject	Port of Gladstone Channel Duplication EIS – Hydrodynamic modelling and coastal processes – ADCP baseline data collection monitoring		

1 Background

As part of the Port of Gladstone Channel Duplication EIS it is proposed to collect wave and current data in the vicinity of the project works for hydrodynamic model calibration and validation purposes. The Commonwealth Government Guidelines for the EIS require that any modelling be in accordance with the “Guidelines for the Use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park” issued by GBRMPA (GBRMPA 2012). The baseline information requirements within the GBRMPA hydrodynamic modelling guidelines state that:

“For dredging campaigns that are predicted to last longer than one month, then a minimum of twice the duration of the dredging campaign worth of baseline data is required to account for seasonal variation. For example, if the dredging campaign is 2 months, then at least 4 months of baseline data is required. For wind data collection, six to eight months of baseline data is required.” (Item 11 of the guidelines)

“Baseline data must be measured in close proximity to the dredging and disposal sites and include metocean parameters such as tidal range, wave height, water current, wind direction and intensity and sediment dynamics.” (Item 12 of the guidelines)

The hydrodynamic and wave models to be used in this study have already undergone substantial calibration and validation within the inner harbour as part of previous studies. This data collection program is intended to provide additional model validation data in outer harbour areas in the vicinity of proposed dredging and dredge material placement activities.

2 Proposed Baseline Data Collection Program

The baseline data collection program described below is proposed for the Channel Duplication EIS in order to provide adequate data for model calibration and validation purposes, and satisfy the requirements of the GBRMPA modelling guidelines for current and wave data.

- Six monitoring sites – refer to Figure 1 for indicative locations (subject to further refinement and approval by the Harbour Master):
 - One site near the East Banks Expansion Dredge Material Placement Area (DMPA) (Site 1)
 - Two sites near the channel dredging activity (Site 2 near the Golding Cutting, Site 3 near the Gatcombe Channel)
 - One site in the lee of the proposed West Banks Island Reclamation DMPA (Site 4)
 - One site near the Port Central Expansion Reclamation DMPA (Site 5)
 - One site in East Channel at the southern end of Facing Island (Site 6)

- Four bottom-mounted ADCP instruments which collect data on 3D currents, water levels and waves will be in the water continuously for 12 months:
 - One instrument deployed continuously for 12 months at the East Banks DMPA (Site 1) to provide a full 12 months of seasonal data, particularly large scale ocean current influences and seasonal waves. Water levels will be recorded every 6 minutes, and wave conditions at least every 2 hours.
 - One instrument deployed continuously for 12 months in the harbour near the channel and the West Banks Island Reclamation DMPA (Site 4) to provide seasonal waves within the harbour as well as a full 12 months of harbour currents at one site
 - The remaining instruments deployed for two three-month periods at each of the other four sites to provide:
 - 12 months of wave and current data in the vicinity of the dredging (6 months at each of Sites 2 and 3, not continuous)
 - Seasonal data (two three-month periods) including waves and currents in near-shore areas at the Port Central Expansion DMPA and the southern end of Facing Island (6 months at each of Sites 5 and 6, not continuous)
- In addition to the above, targeted current measurements will also be collected across transects in the vicinity of island/reclamation DMPA options (near Sites 4 and 5) and off the southern end of Facing Island (near Site 6) to validate current distributions and patterns across the channels. The approximate locations of the transects are shown in Figure 1 (subject to further refinement).
- Collection of co-incident turbidity data (using nephelometers mounted approximately 0.5m above the bed) at each site during ADCP data collection to establish the relationships between waves, currents and turbidity (NTU)/total suspended sediments (TSS) concentrations. Water samples will be collected at the nephelometer location to enable calibration of the NTU-TSS relationship.
- Maintenance and servicing of ADCP equipment and nephelometers will occur every 6 weeks to minimise the risk of data loss
- Turbidity profiling at each ADCP/nephelometer deployment location and water sample analysis for TSS and particle size distribution (PSD) will be undertaken during each 6 week servicing site visit to provide information for calibration and correlation of turbidity data to TSS. This will be supplemented with existing and Channel Duplication EIS baseline turbidity/TSS data collected from other water quality monitoring sites within the harbour.

For other metocean parameters we intend to use available data from existing measurement programs. Long term local wind data is available from the BOM Gladstone Radar station, to be supplemented with local data from GPCL weather stations. Boundary conditions for the regional hydrodynamic and wave models will be obtained from offshore BoM and AIMS weather stations, as well as global atmospheric model outputs (e.g. NCEP). Long term tide recordings are available from the MSQ gauges at South Trees and Auckland Point. There is also offshore wave data available (2009 onwards) from the DEHP Gladstone Waverider buoy. The locations of these data sources are shown in Figure 2.

3 Compliance with GBRMPA Modelling Guidelines

The proposed Channel Duplication EIS hydrodynamic modelling baseline data collection programme is considered appropriate to provide sufficient baseline data for model calibration and validation purposes, and to properly characterise the full range of seasonal conditions in the vicinity of the dredging and potential dredge material placement sites. The data can also be used to provide appropriate relationships between inshore and offshore locations so that continuous wind, offshore wave and tide recordings from permanent monitoring sites can be used to infer a longer time series of relevant metocean parameters at locations within the harbour. The validated hydrodynamic and wave

models will be used to simulate a representation of the entire dredging campaign under a range of possible seasonal conditions, amongst a range of other simulation scenarios and sensitivity testing.

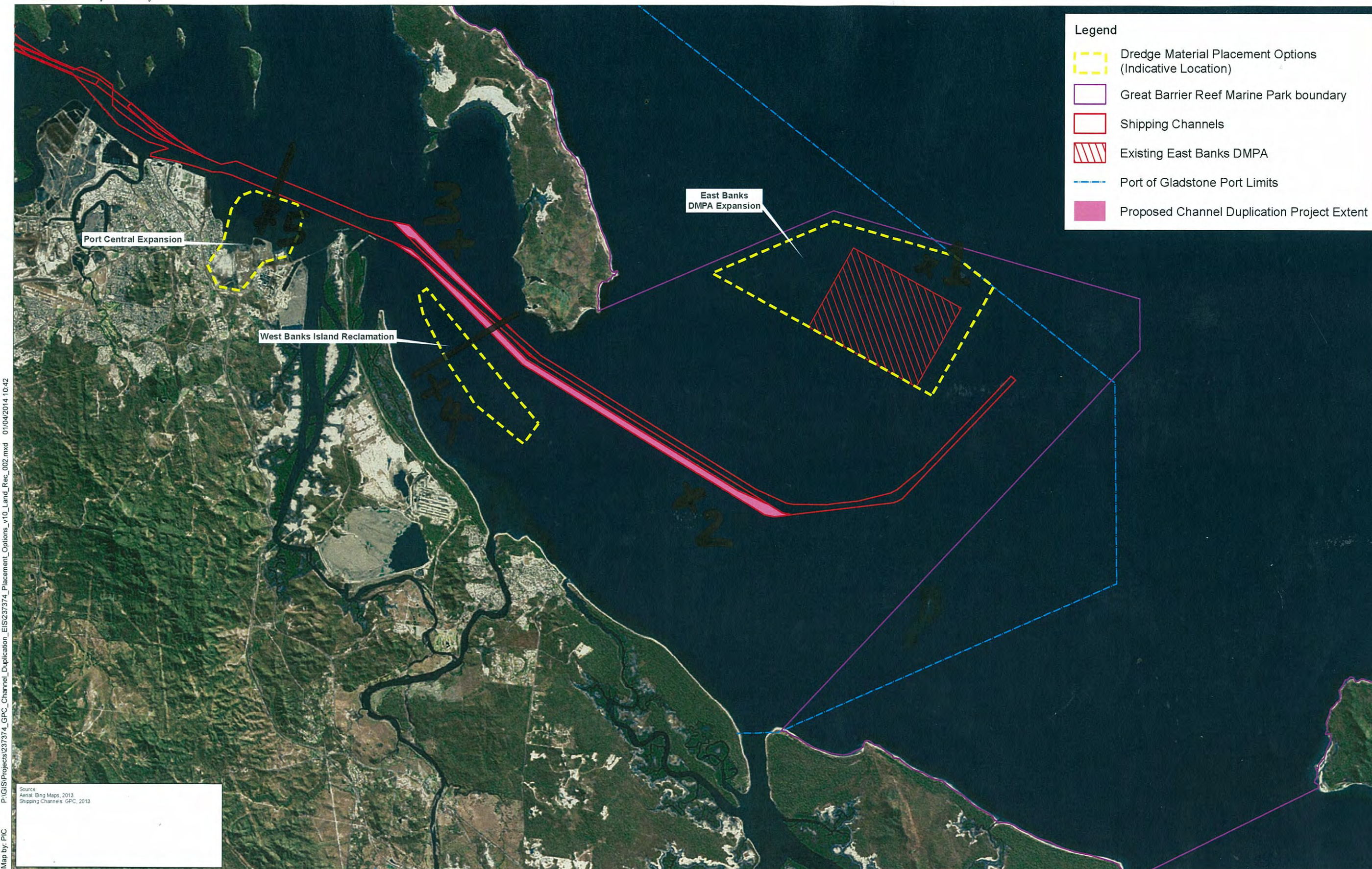
4 Independent Hydrodynamic Modelling Peer Review

The Channel Duplication EIS hydrodynamic modelling peer reviewer (Doug Treloar) has reviewed the proposed baseline data collection program, including this document itself, and his recommendations have been incorporated into the program outlined above.

5 References

GBRMPA (2012): Guidelines for the Use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park. Source:

http://www.gbrmpa.gov.au/__data/assets/pdf_file/0018/26532/Guidelines-on-Hydrodynamics-Modelling-15-Aug-2012.pdf Accessed 7/4/2014.



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Date: 01/04/2014 Version: 1 Job No: 237374

Coordinate system: GDA_1994_MGA_Zone_56

Port of Gladstone Channel Duplication

Draft Figure 1: Indicative Dredge Material Placement Options



Paul Guard

Subject: FW: Port of Gladstone Channel Duplication EIS - wave and current baseline data collection monitoring

From: Kevin Edison [<mailto:kevin.edison@gbrmpa.gov.au>]

Sent: Tuesday, 15 July 2014 8:31 AM

To: Stephen Cole

Cc: tim.ipkendanz@environment.gov.au; Elson Steve (Steve.Elson@ehp.qld.gov.au)

Subject: RE: Port of Gladstone Channel Duplication EIS - wave and current baseline data collection monitoring [SEC=UNCLASSIFIED]

Dear Stephen

Thank you for the opportunity to review the Port of Gladstone Channel Duplication EIS-Hydrodynamic modelling and coastal processes ADCP baseline collection monitoring, dated 20 June 2014.

The Great Barrier Reef Marine Park Authority notes the following:

- The location of all the ADCP baseline site are outside the Great Barrier Reef Marine Park.
- The location of the ADCP sites are in close proximity to proposed dredging and disposal sites.
- There are two sites with continuous 12 months of ADCP data collection one inshore and one further offshore.
- Further the remainder of sites (2, 3, 5 and 6) will be monitored for seasonal variations over two separate 3 month periods.
- That the absence of ADCP sites within the Marine Park effectively limits future consideration of disposal sites offshore and within the Marine Park.
- Existing information that already exists within Gladstone Harbour.
- Whilst we understand that this monitoring program is designed to populate the 3D modelling, incorporation of underwater PAR and the measurement of light extinction coefficients would be highly beneficial. The measurement of light will allow us to determine potential relationships between light-particle size-Turbidity-Total Suspended Solids and ecosystem health.

Further an important consideration is to be able to demonstrate that any modelling undertaken includes the effects of tides, local winds and regional ocean currents (Point 6 of the Guidelines).

In summary, the proposed ADCP baseline data collection monitoring program appears consistent with the Guidelines for the Use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park

Regards,

Kevin Edison

Project Manager - Maritime and Defence
Environmental Assessment and Protection
Great Barrier Reef Marine Park Authority
PO Box 1379

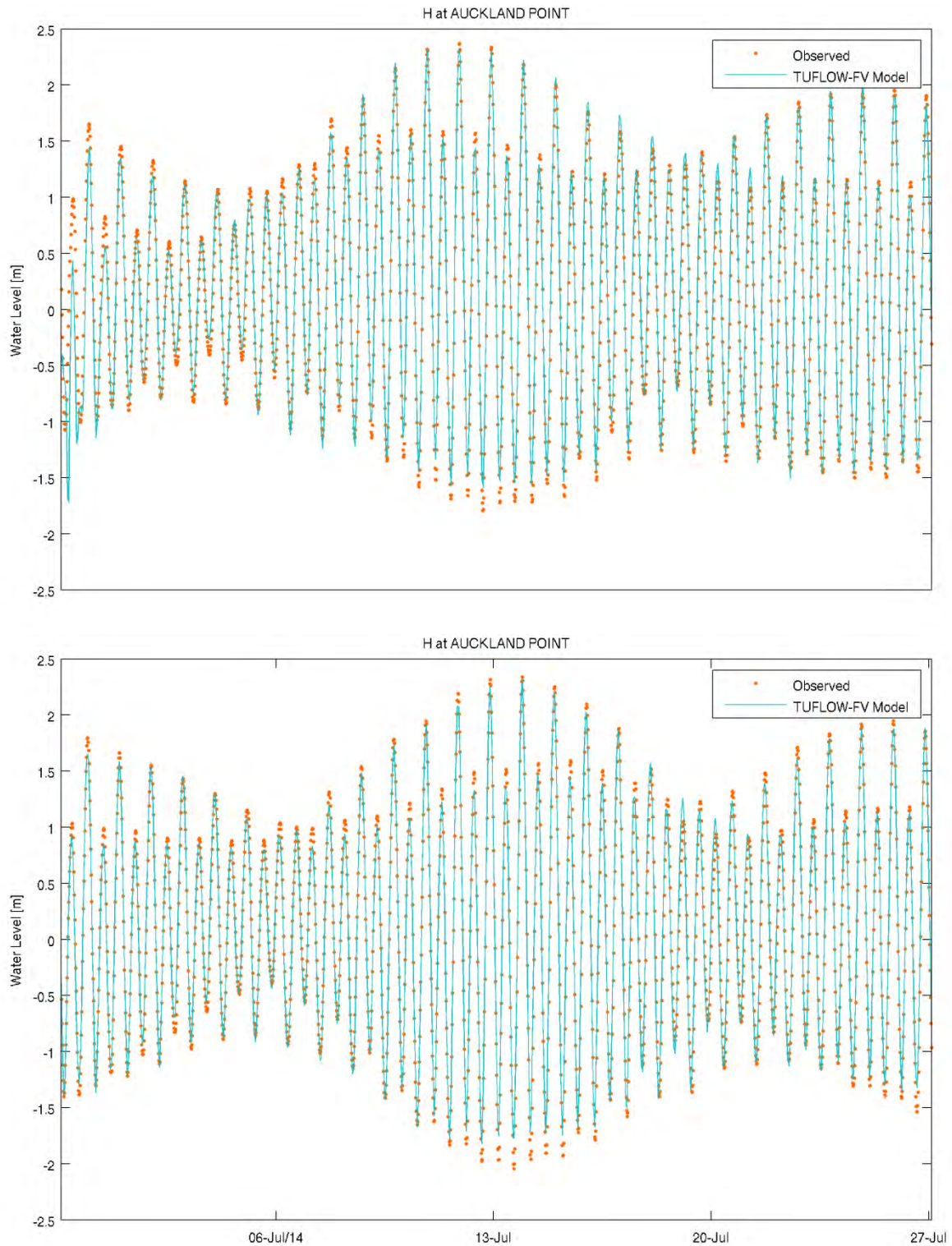
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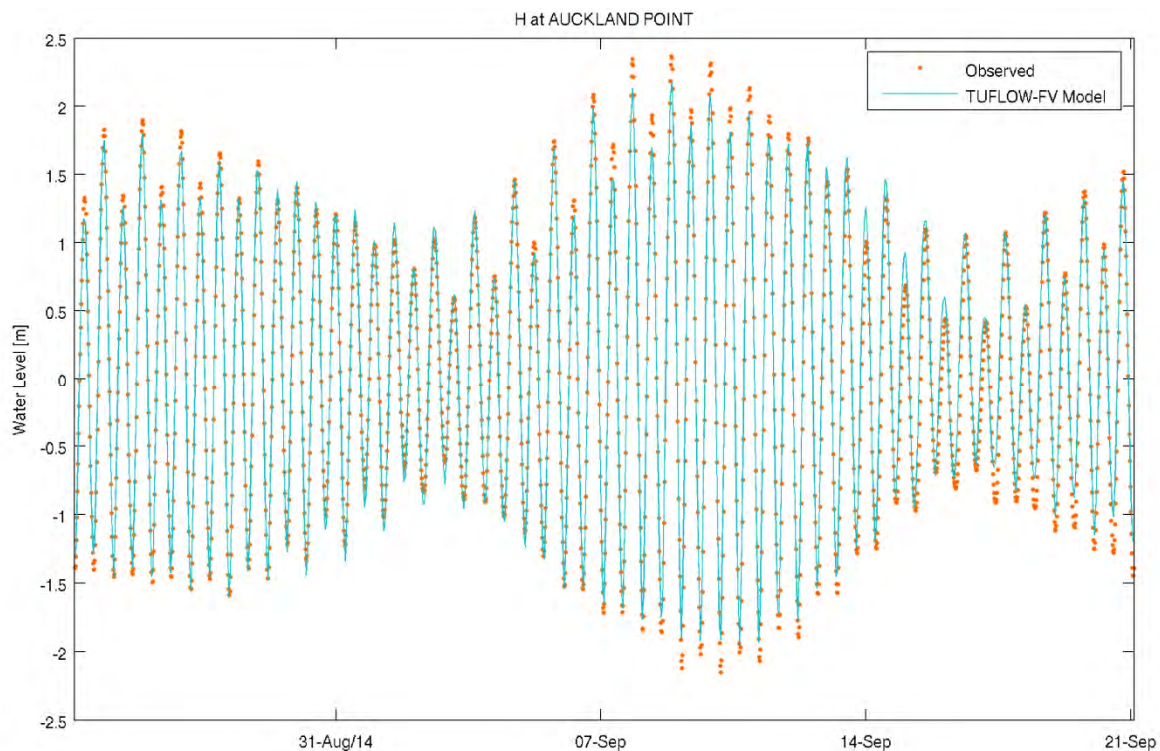
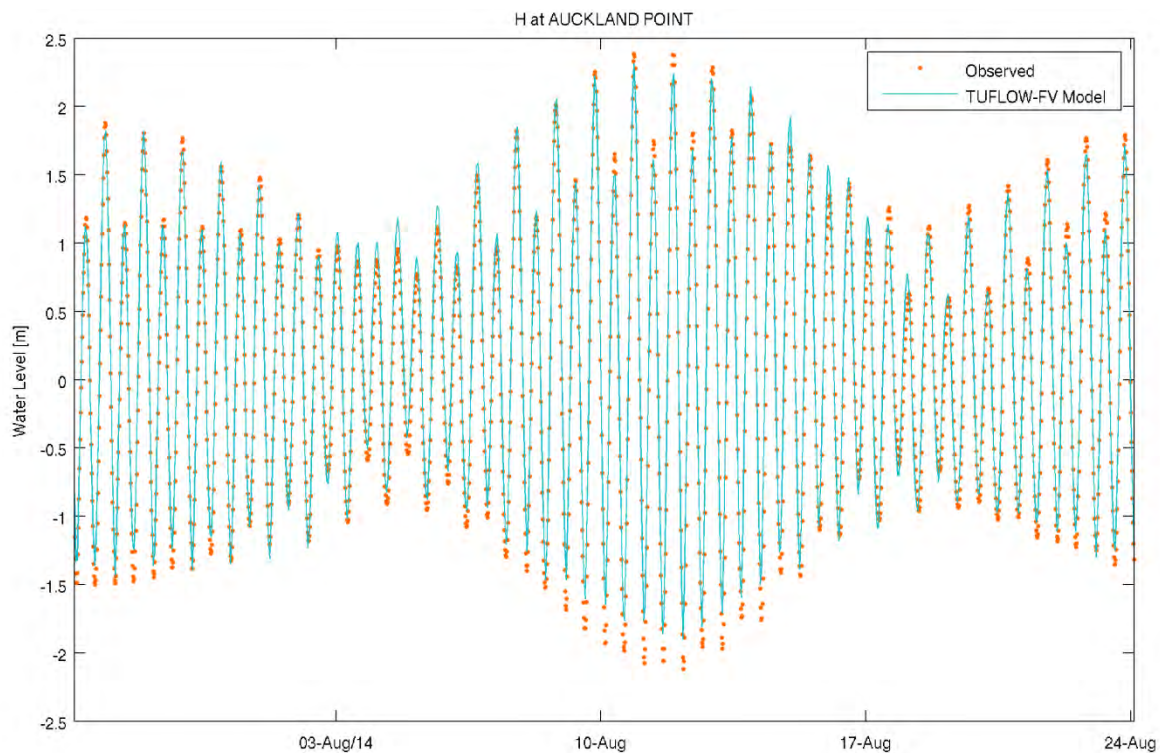
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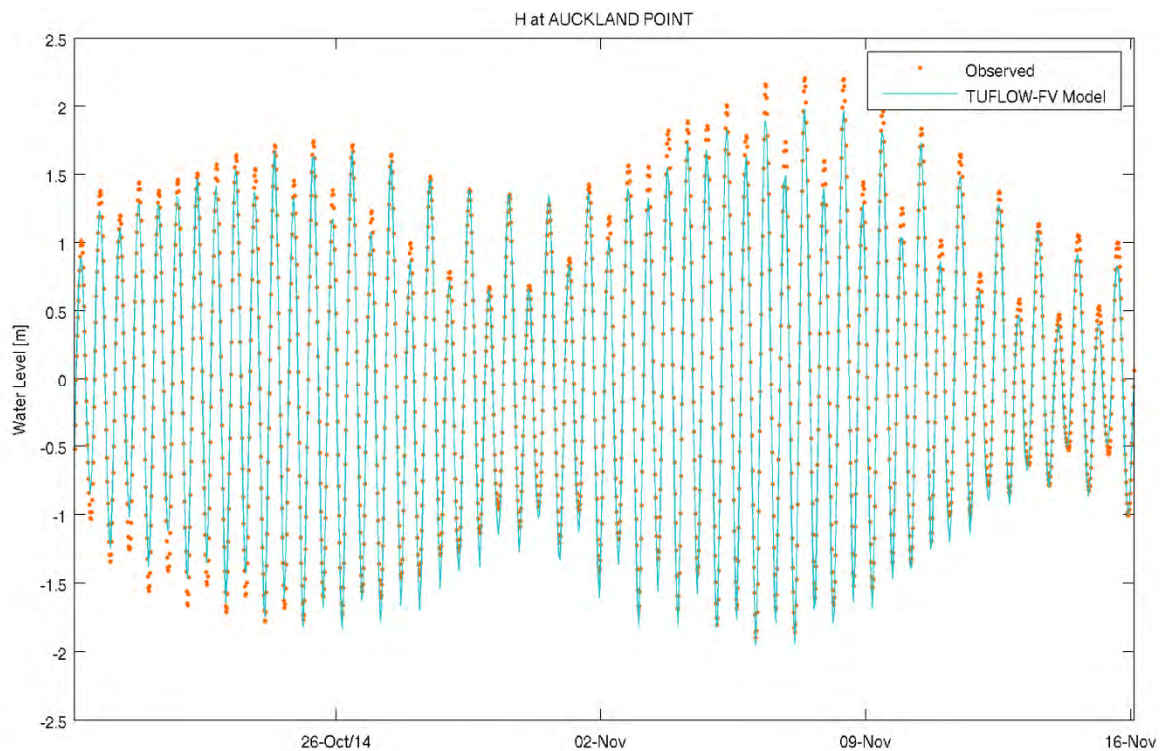
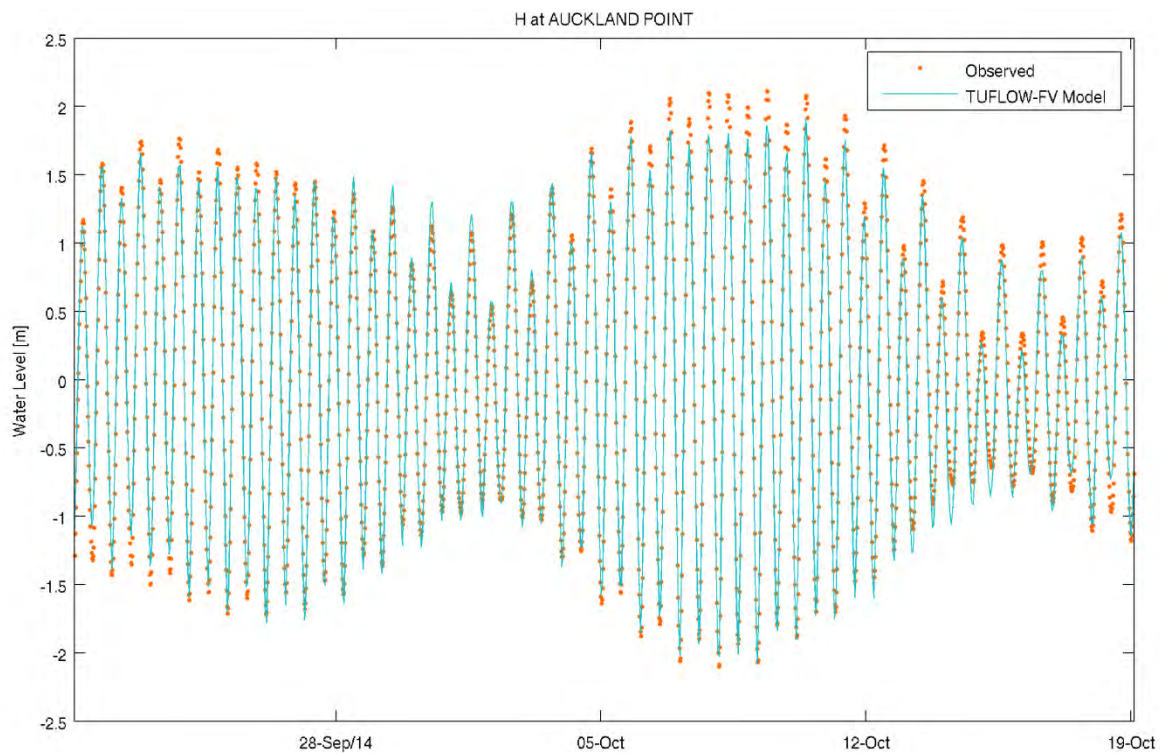
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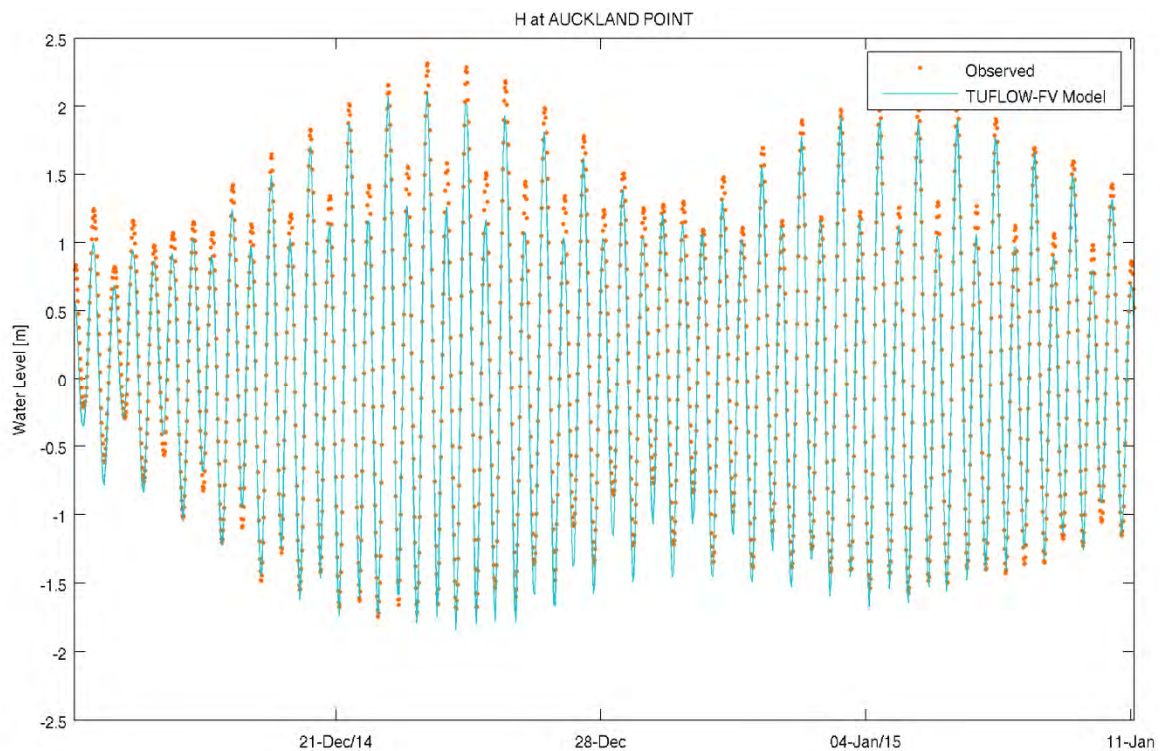
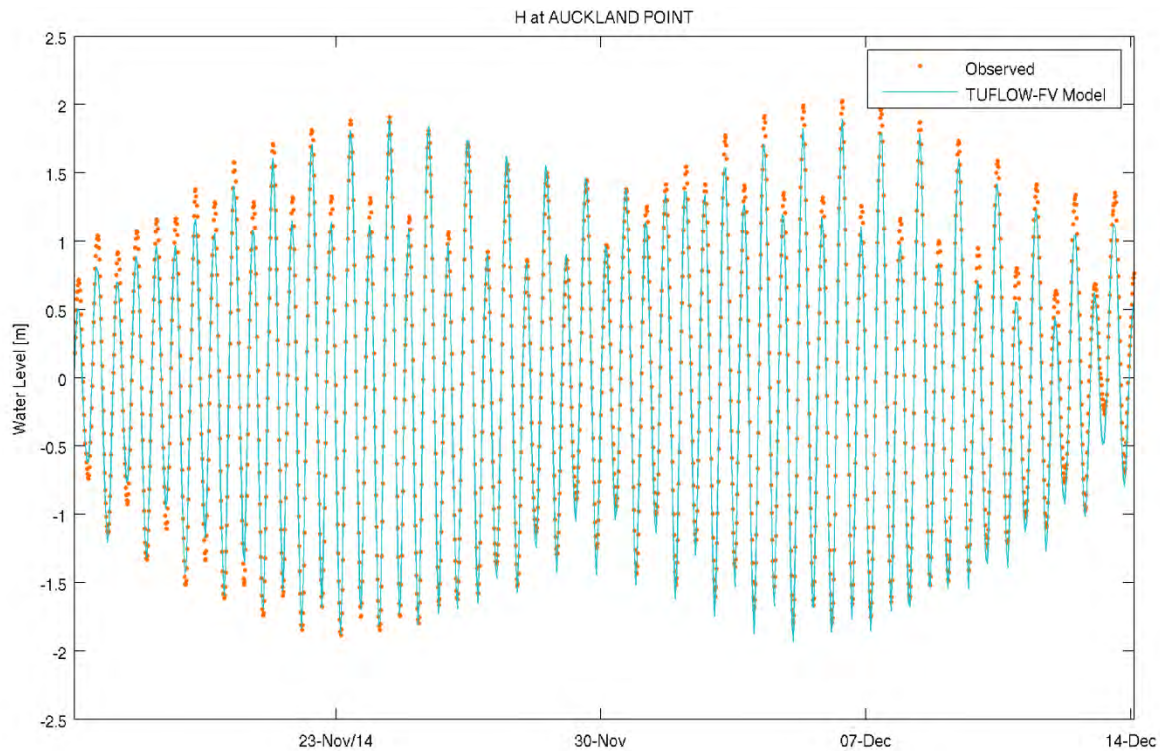
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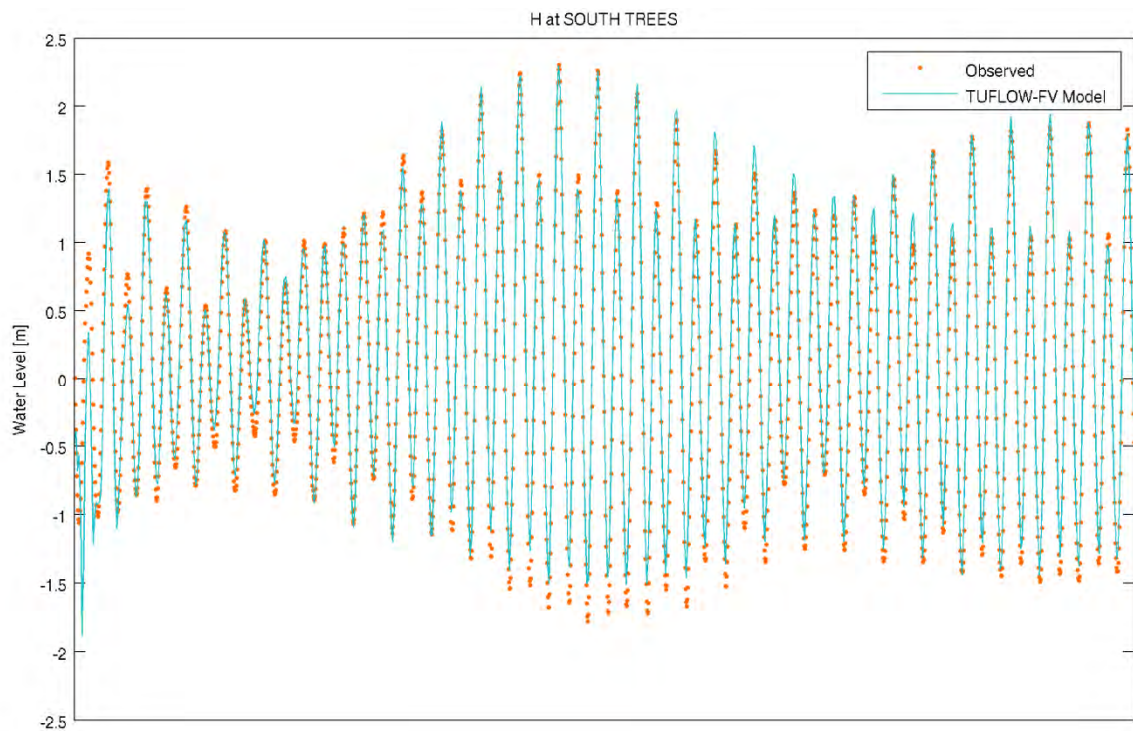
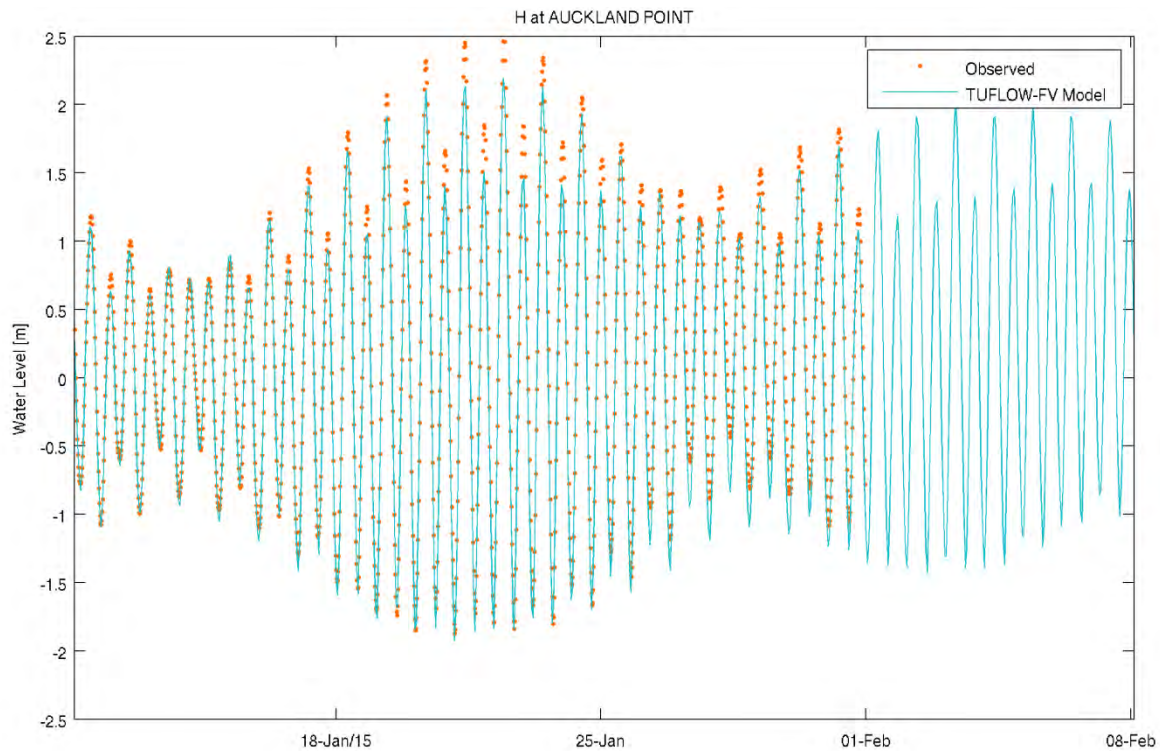
Appendix C Water Level Calibration and Validation Plots

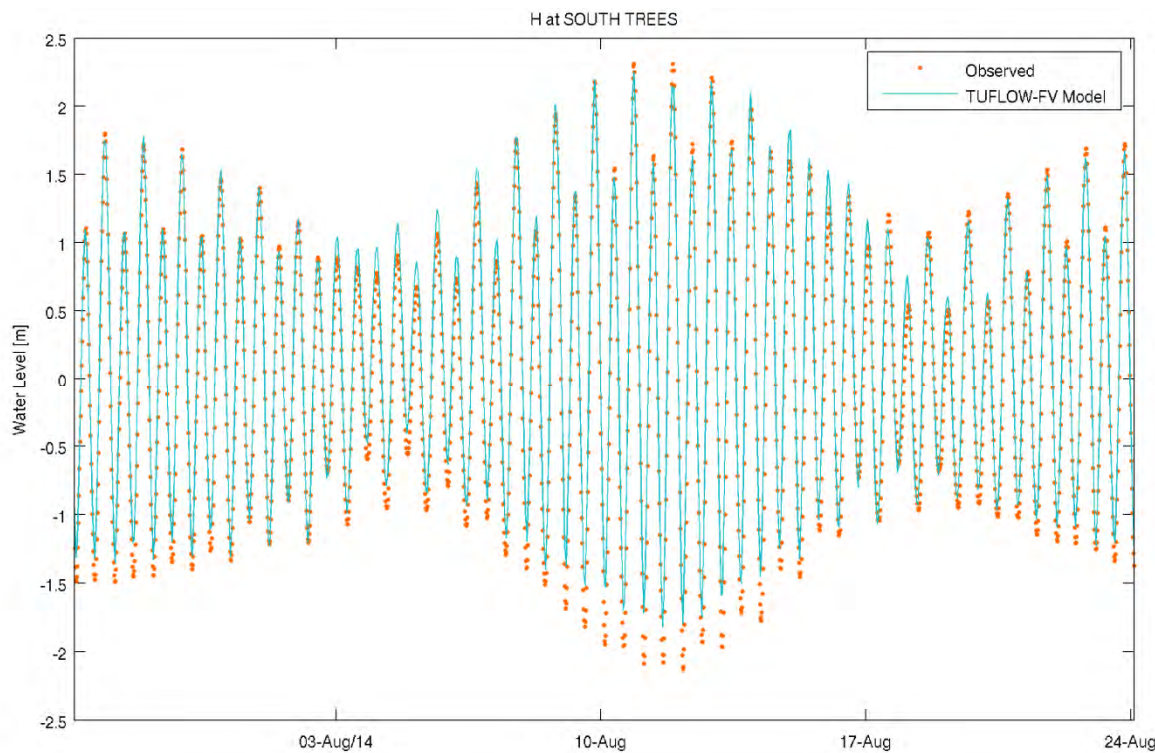
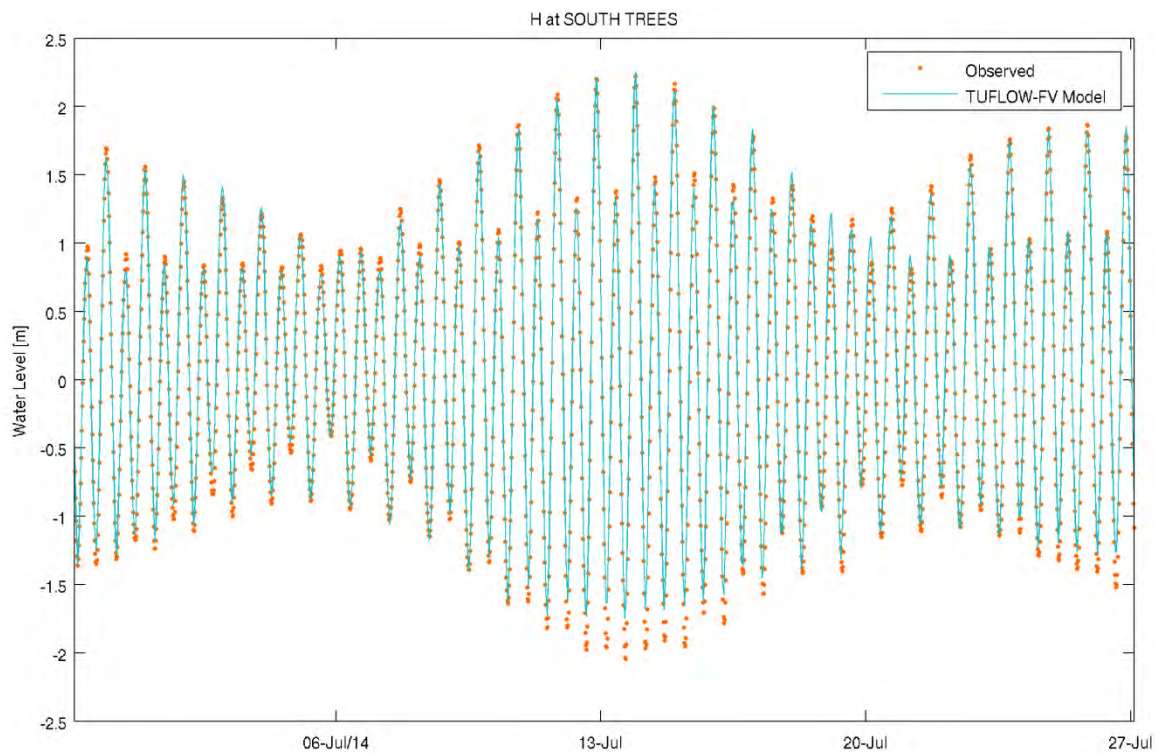


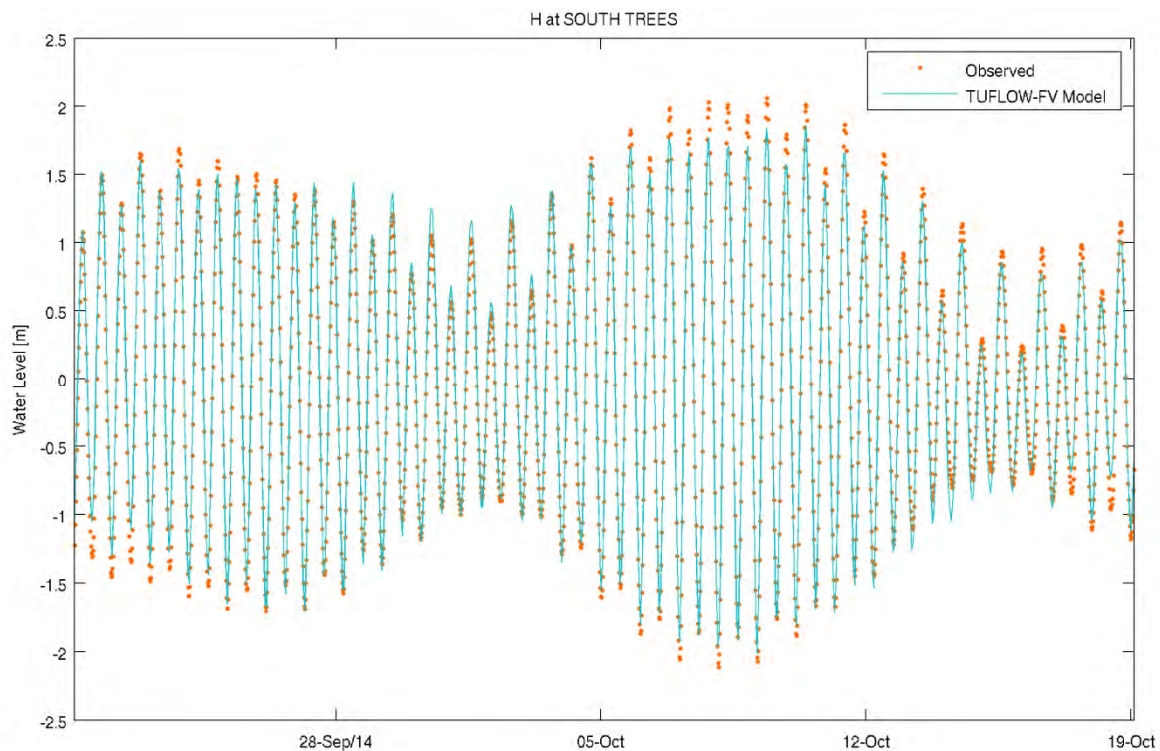
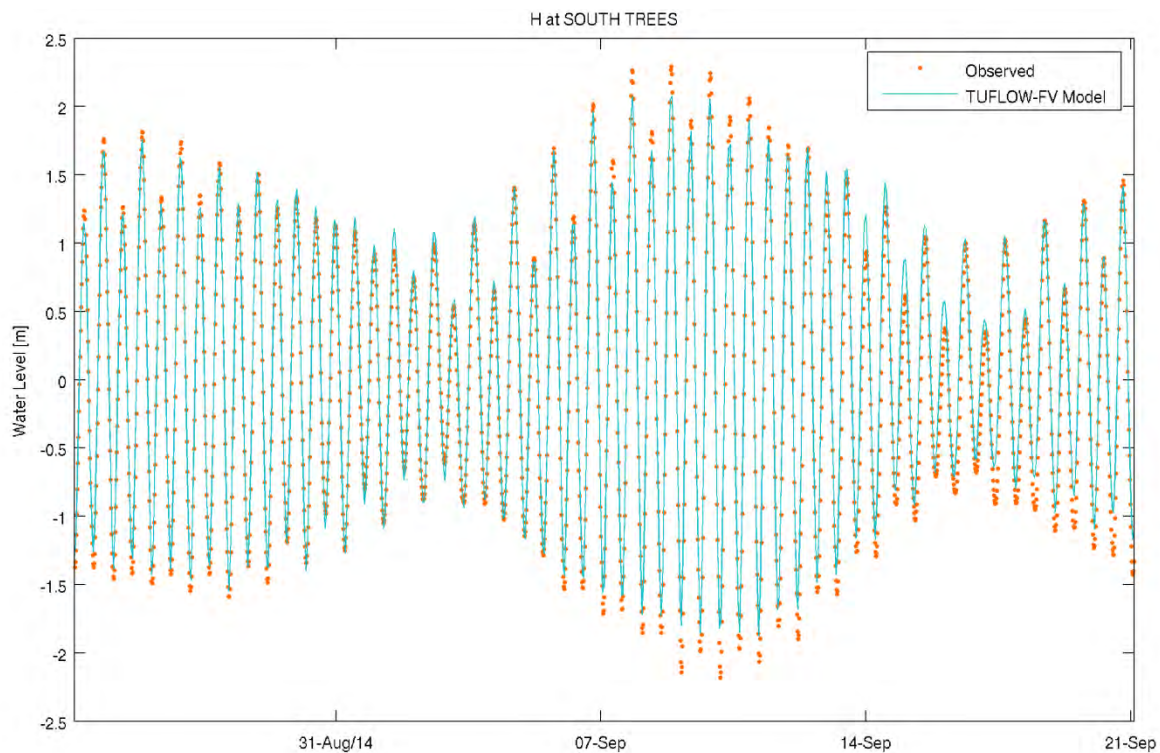


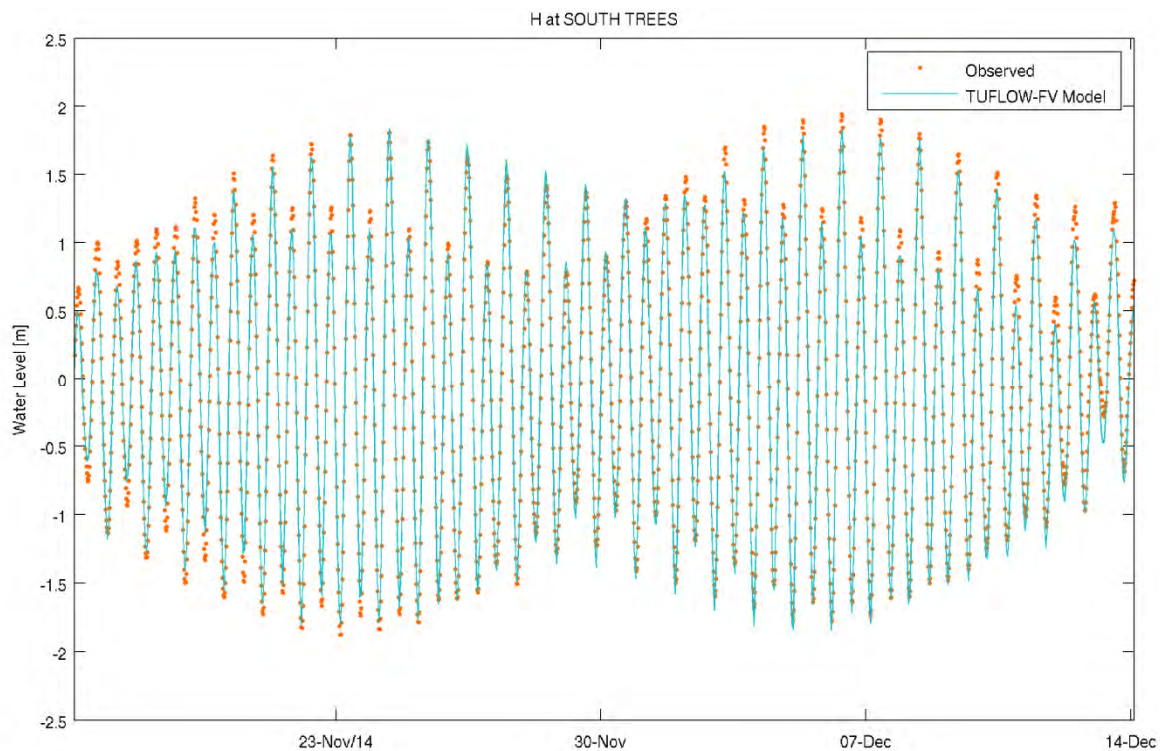
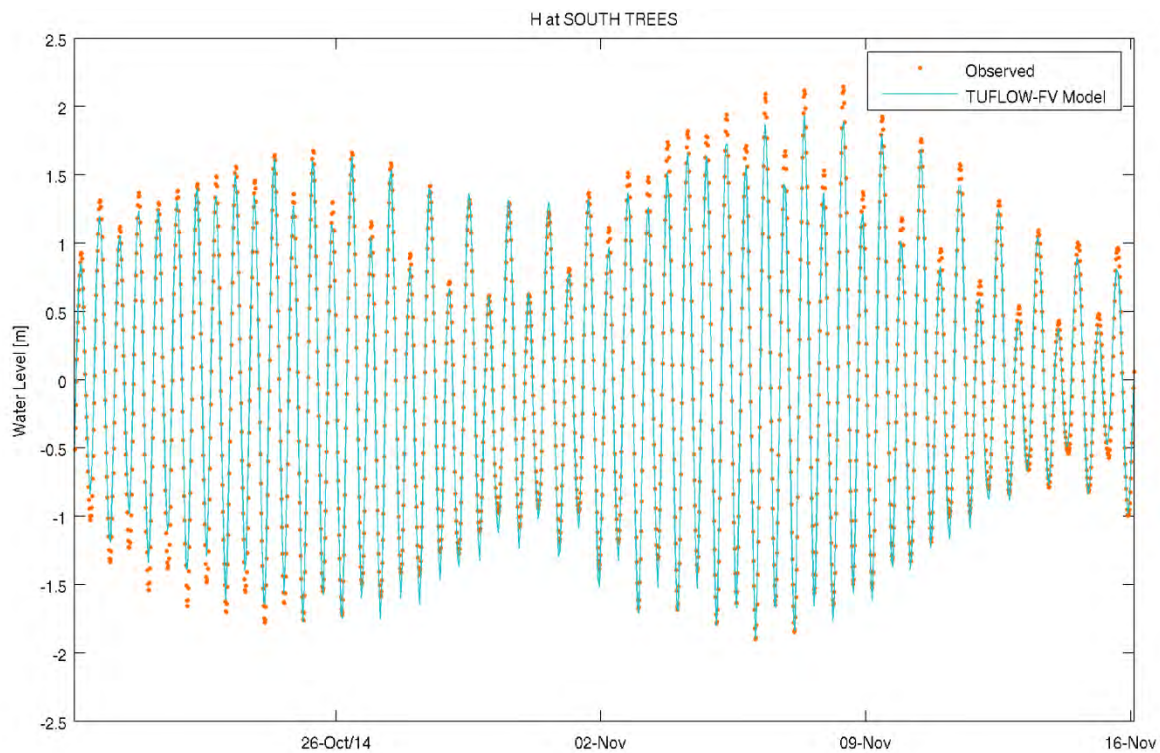


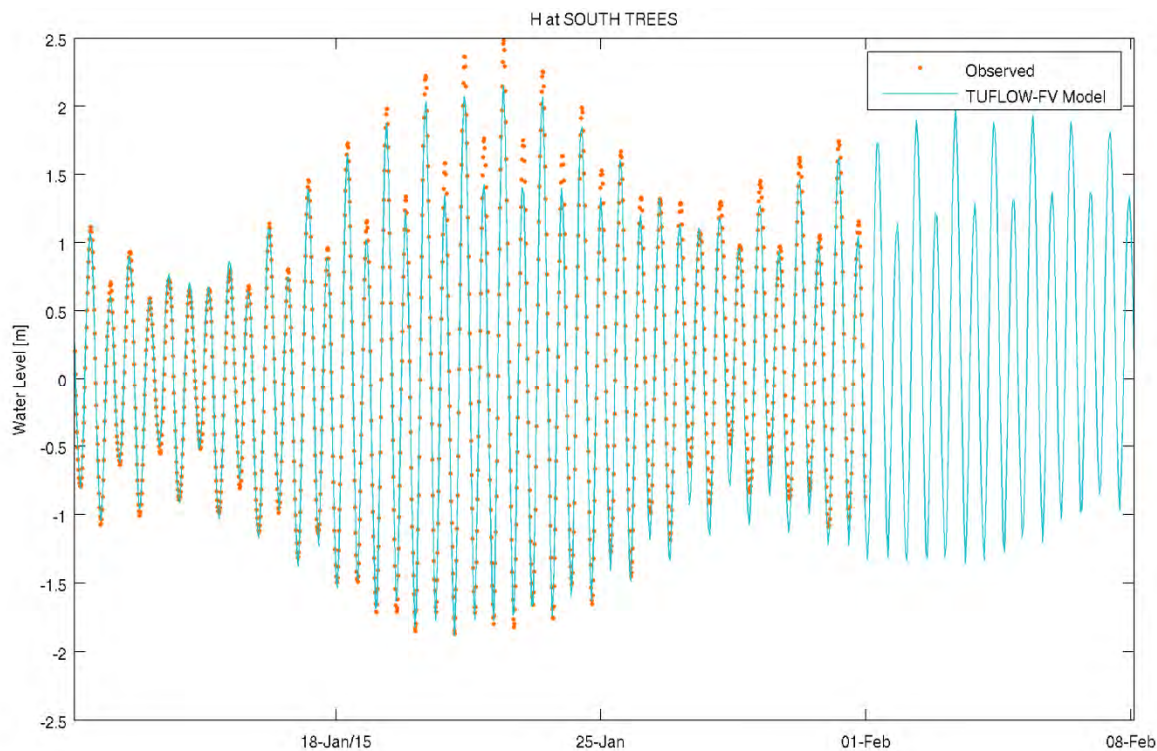
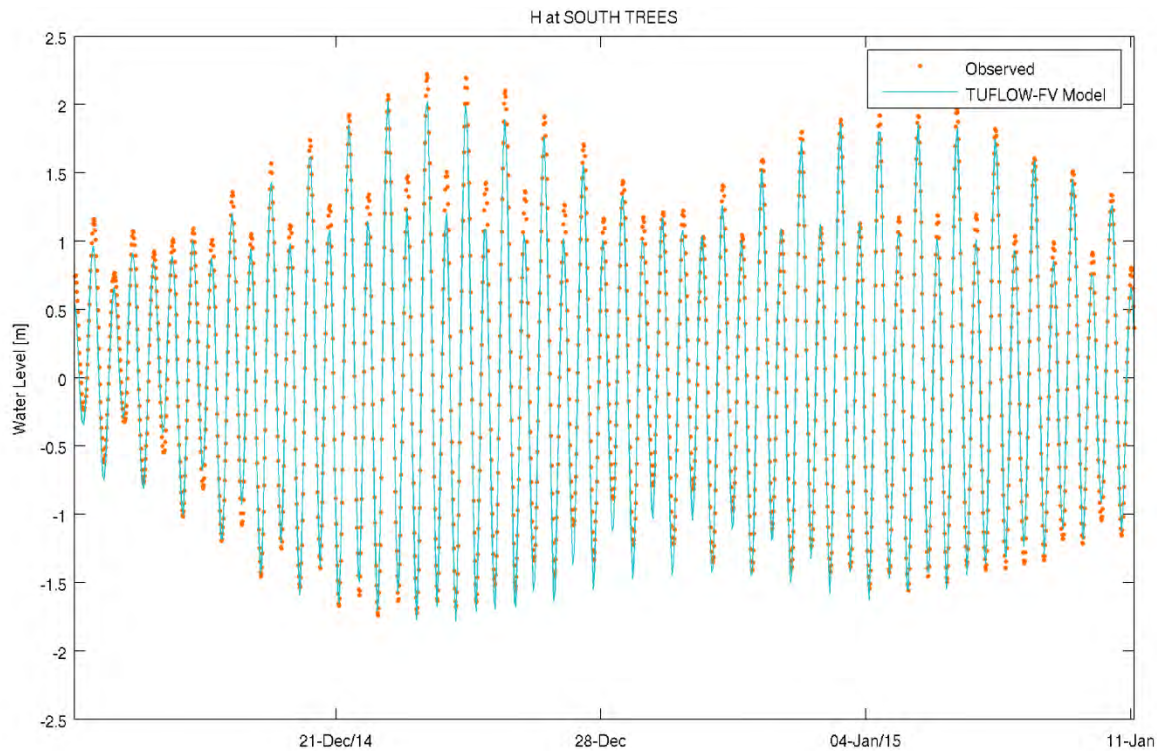




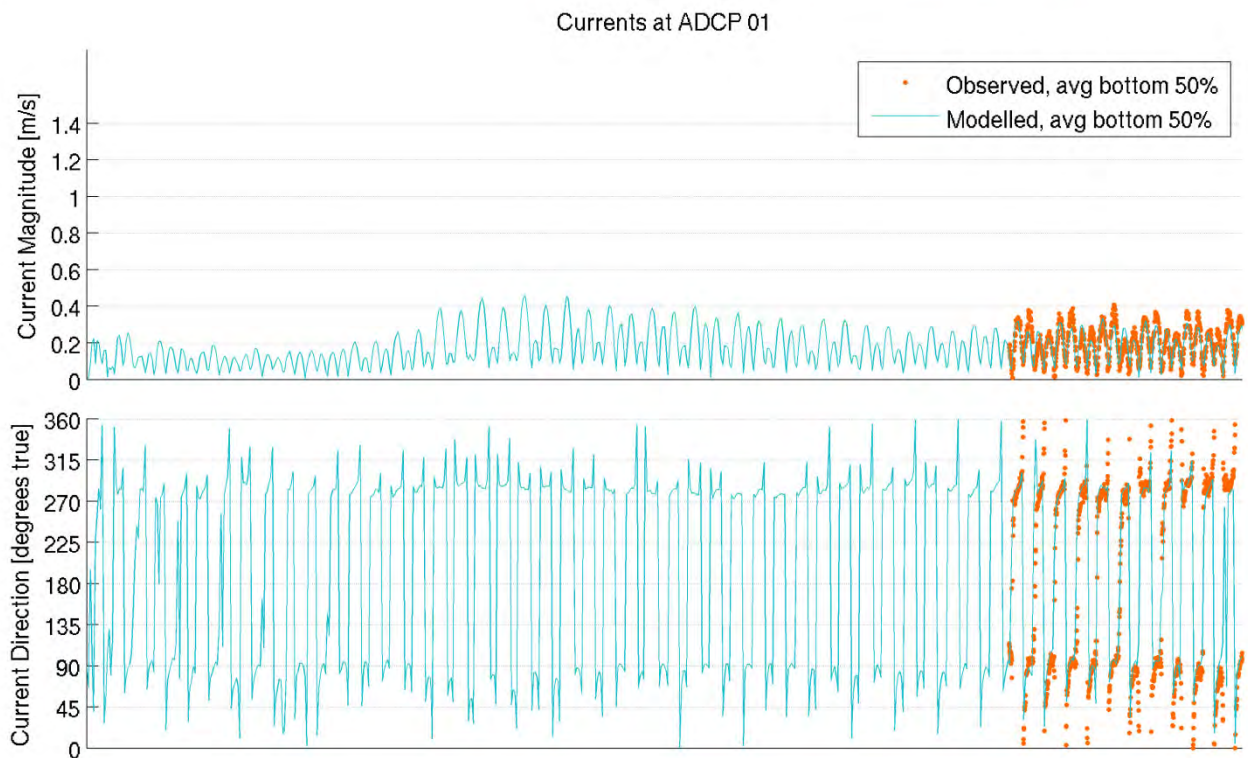
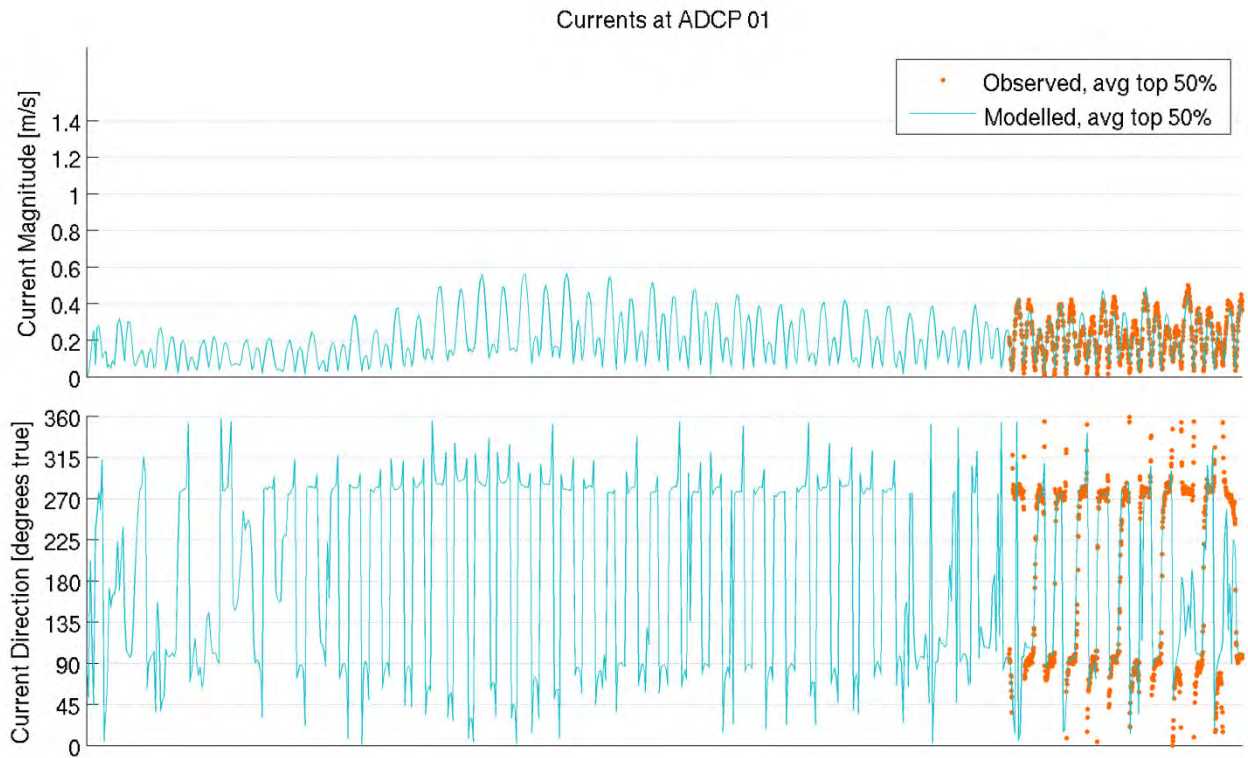


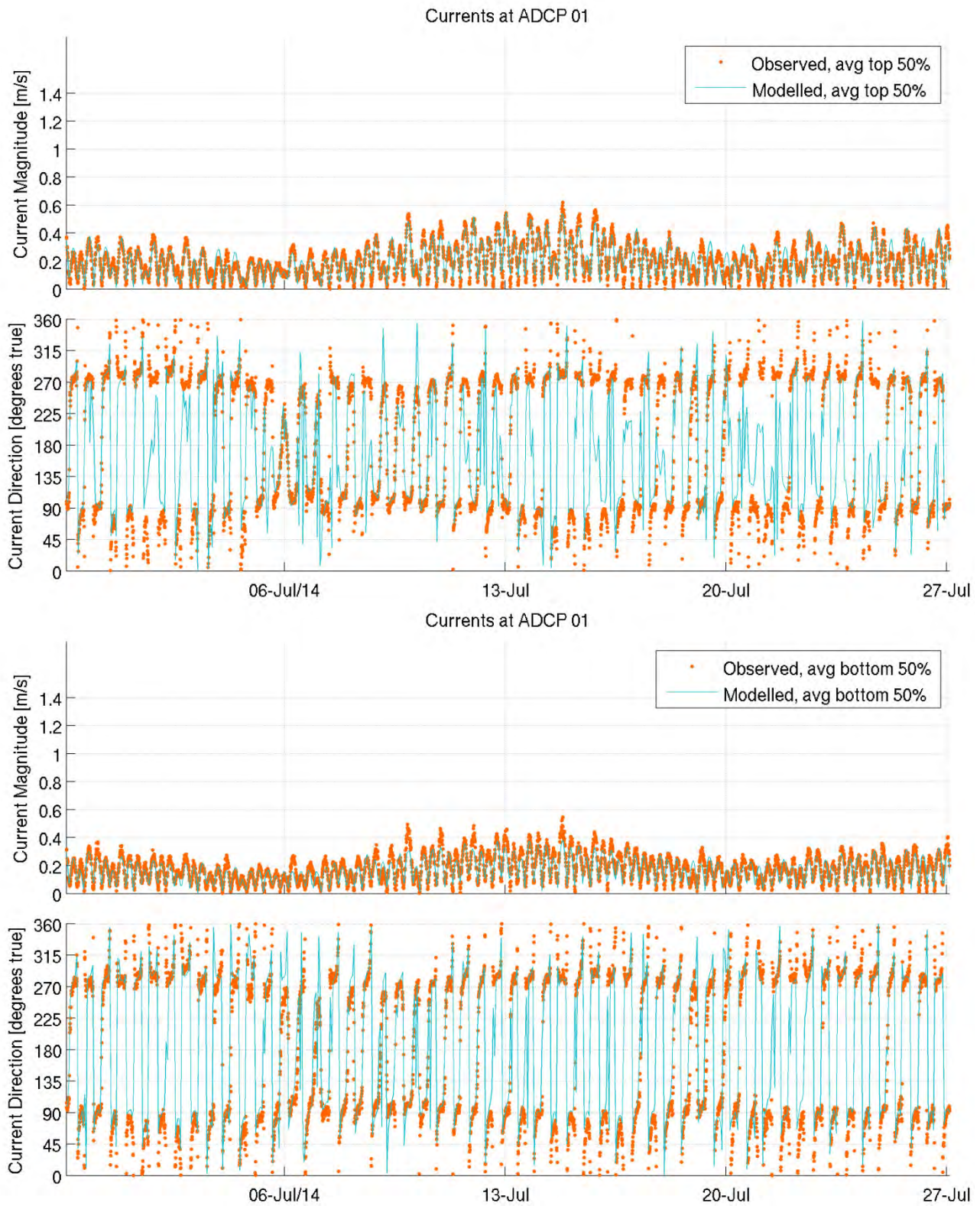


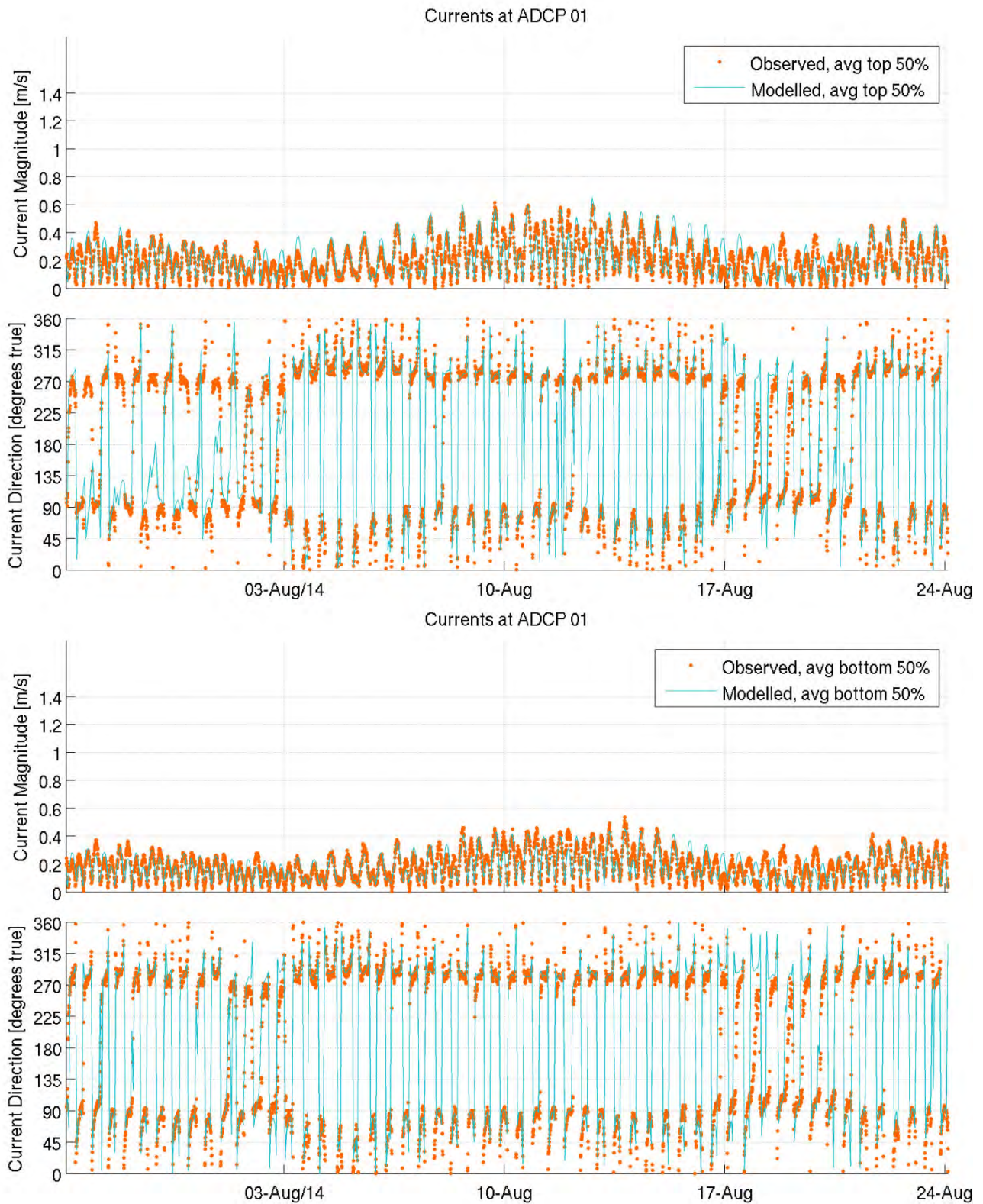


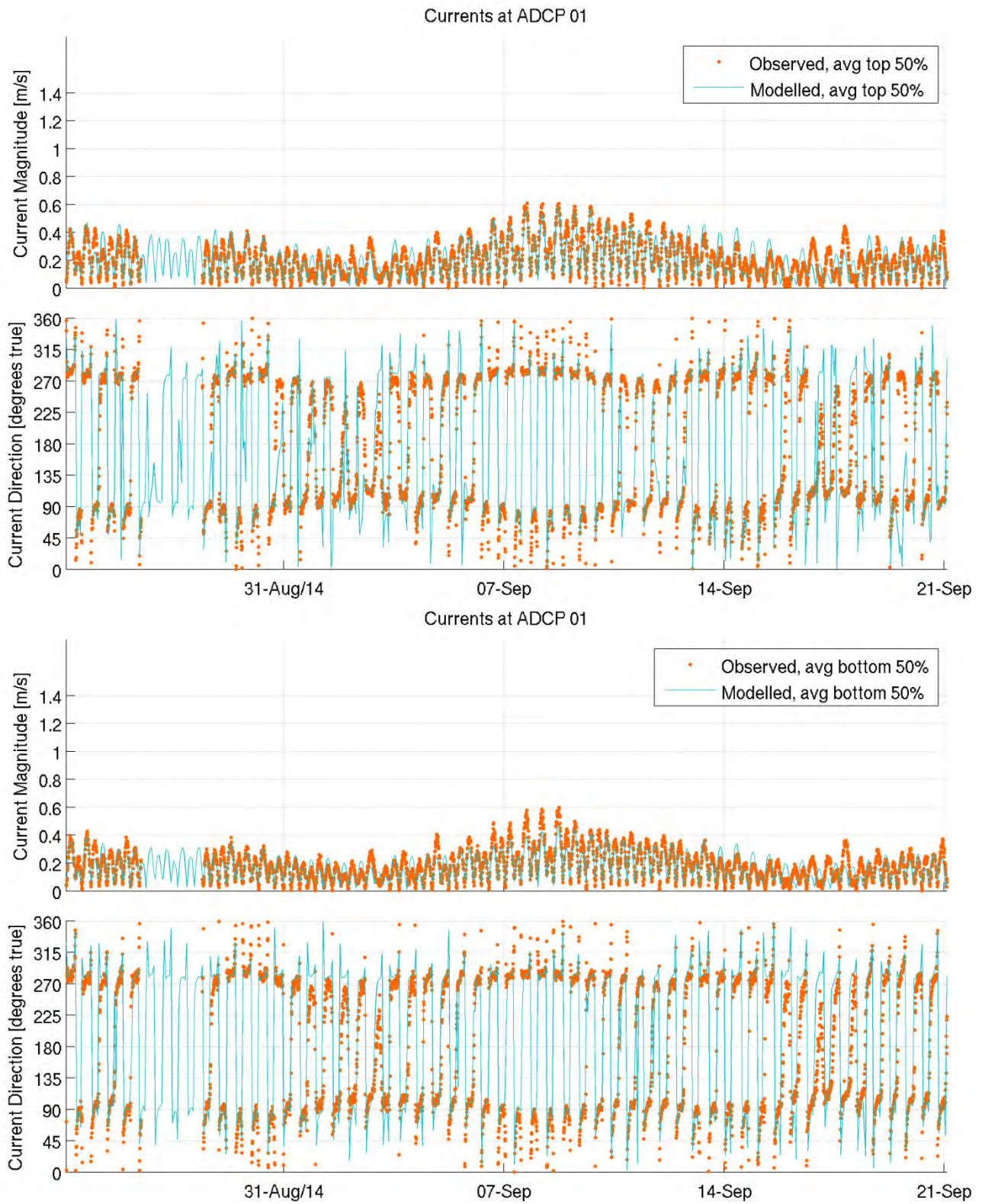


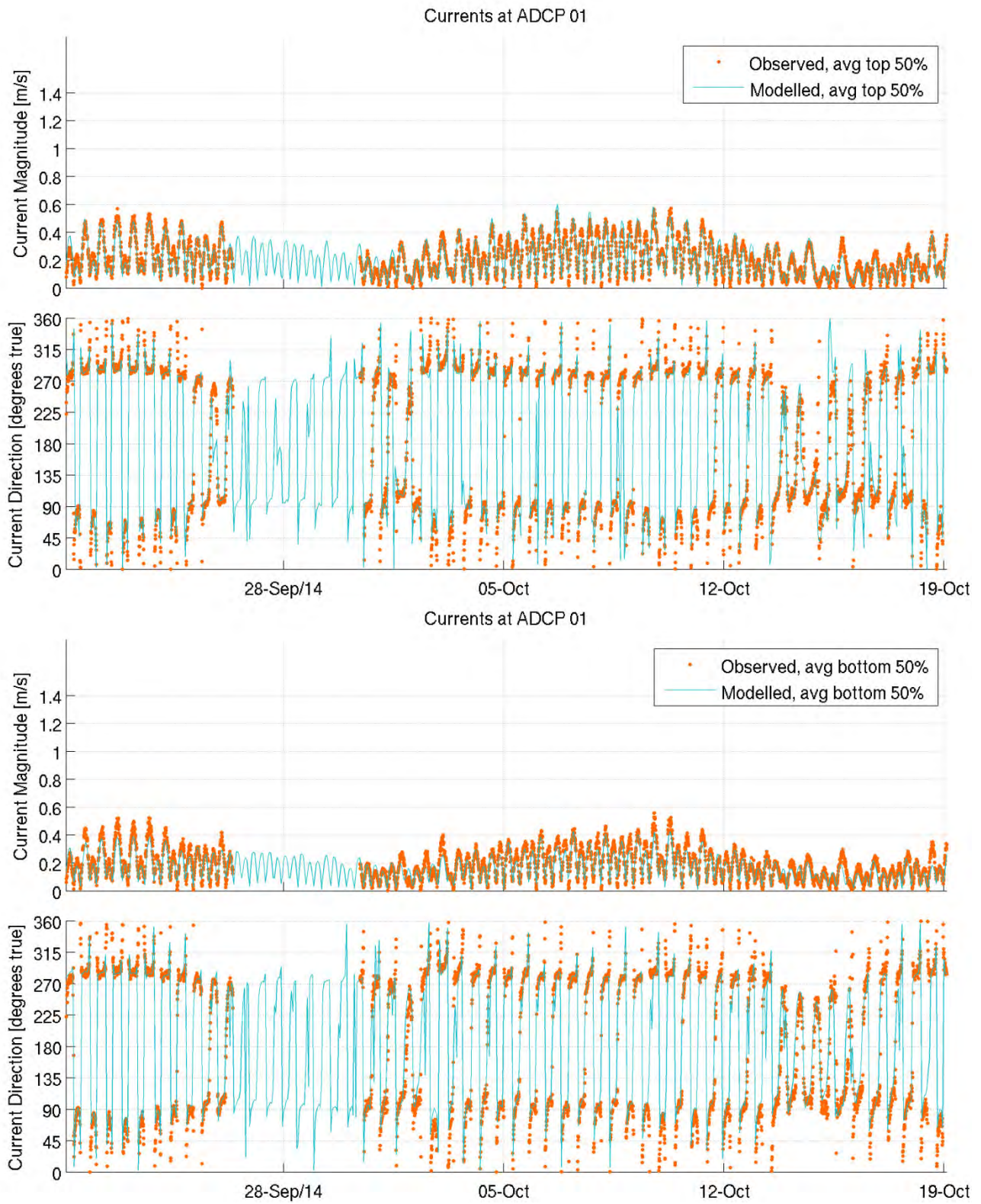
Appendix D Water Velocity Calibration and Validation Plots

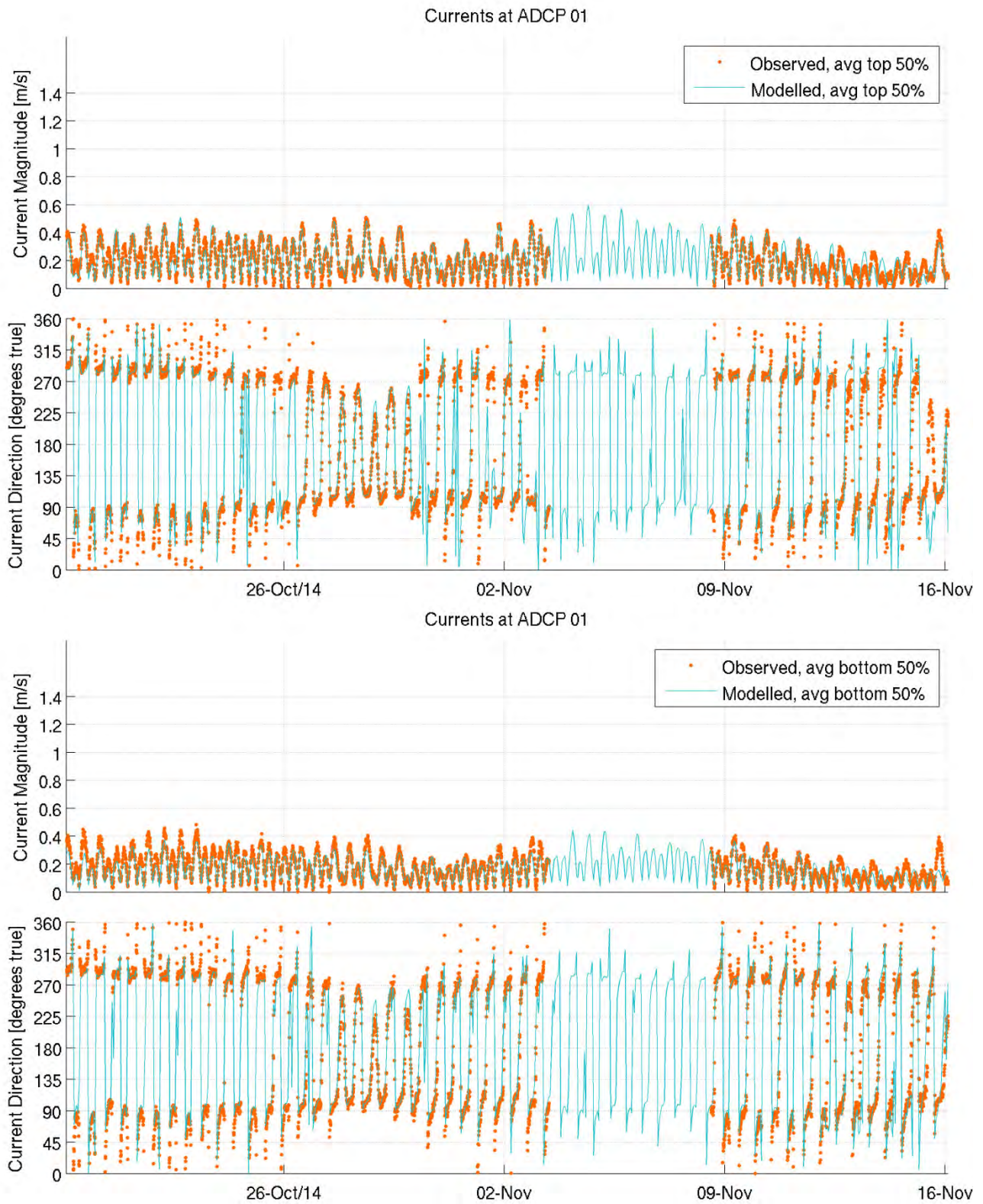


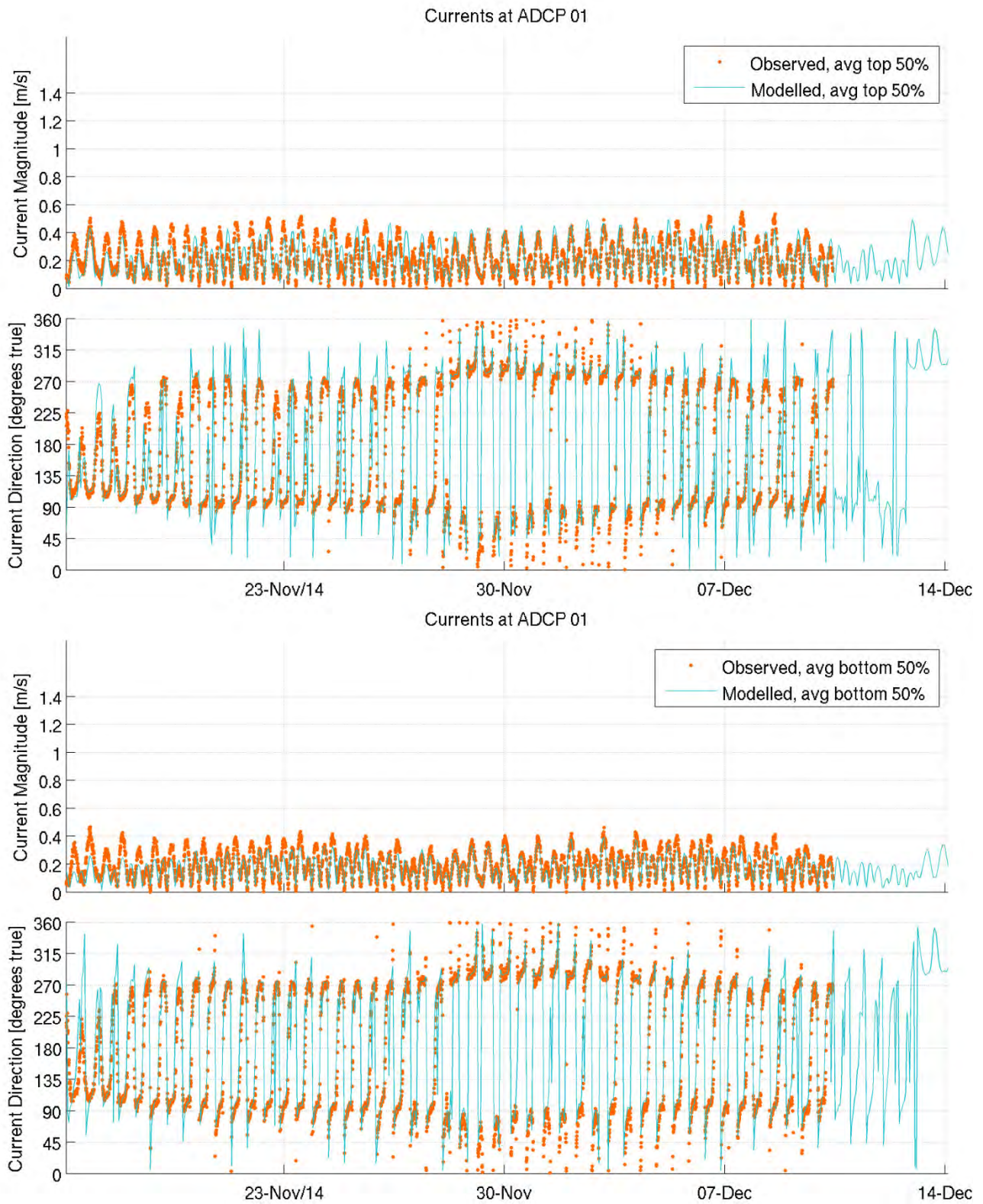


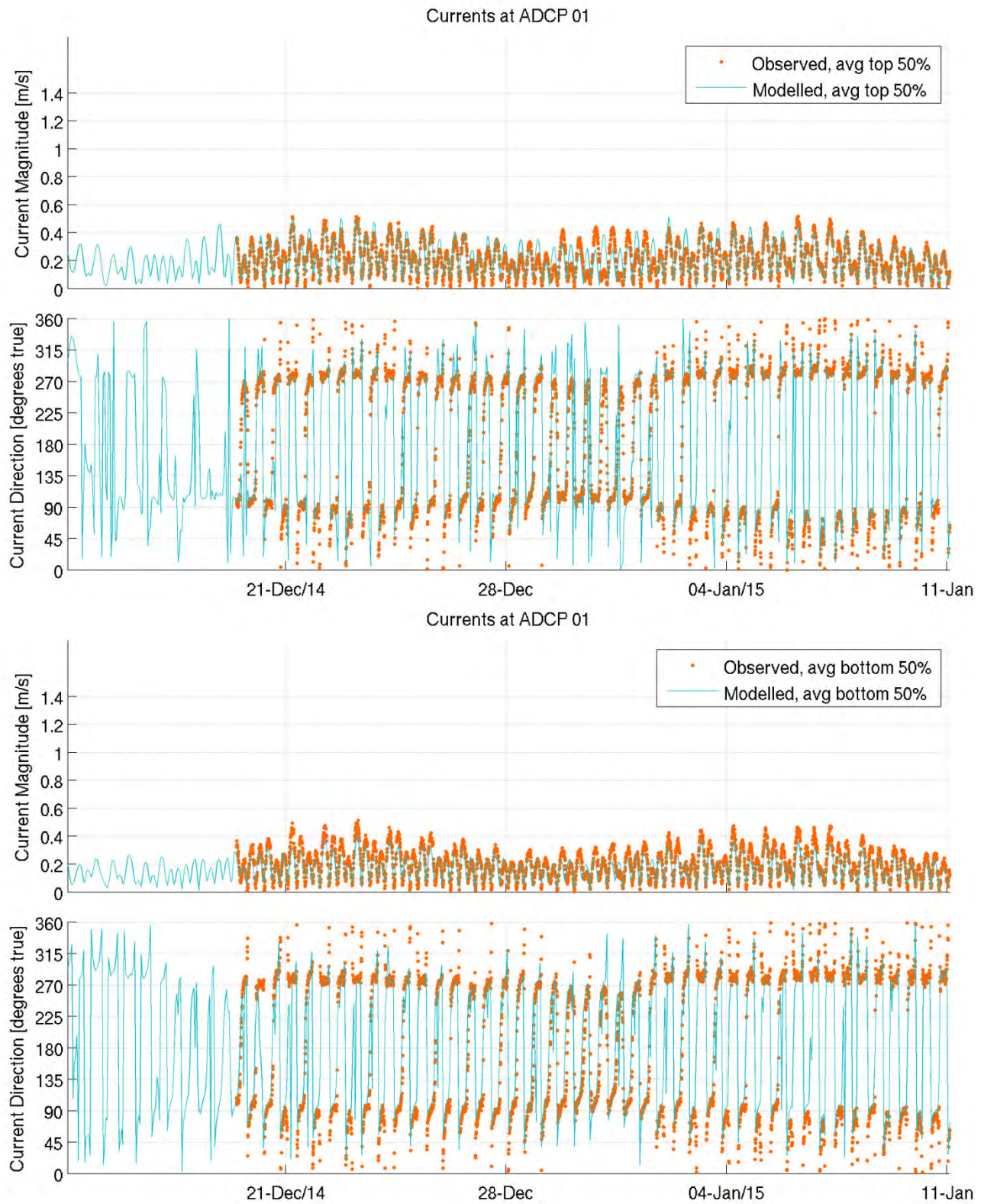


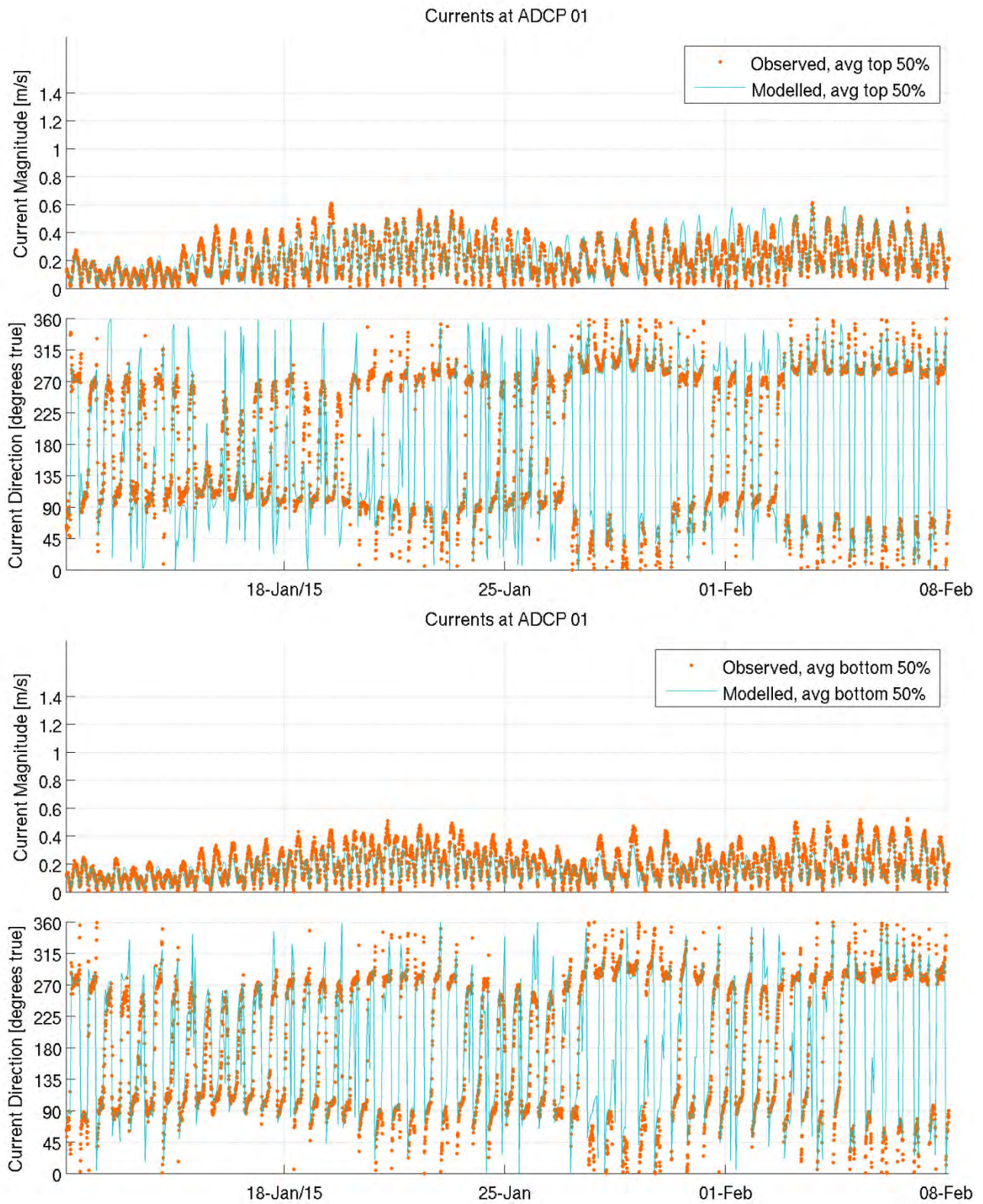


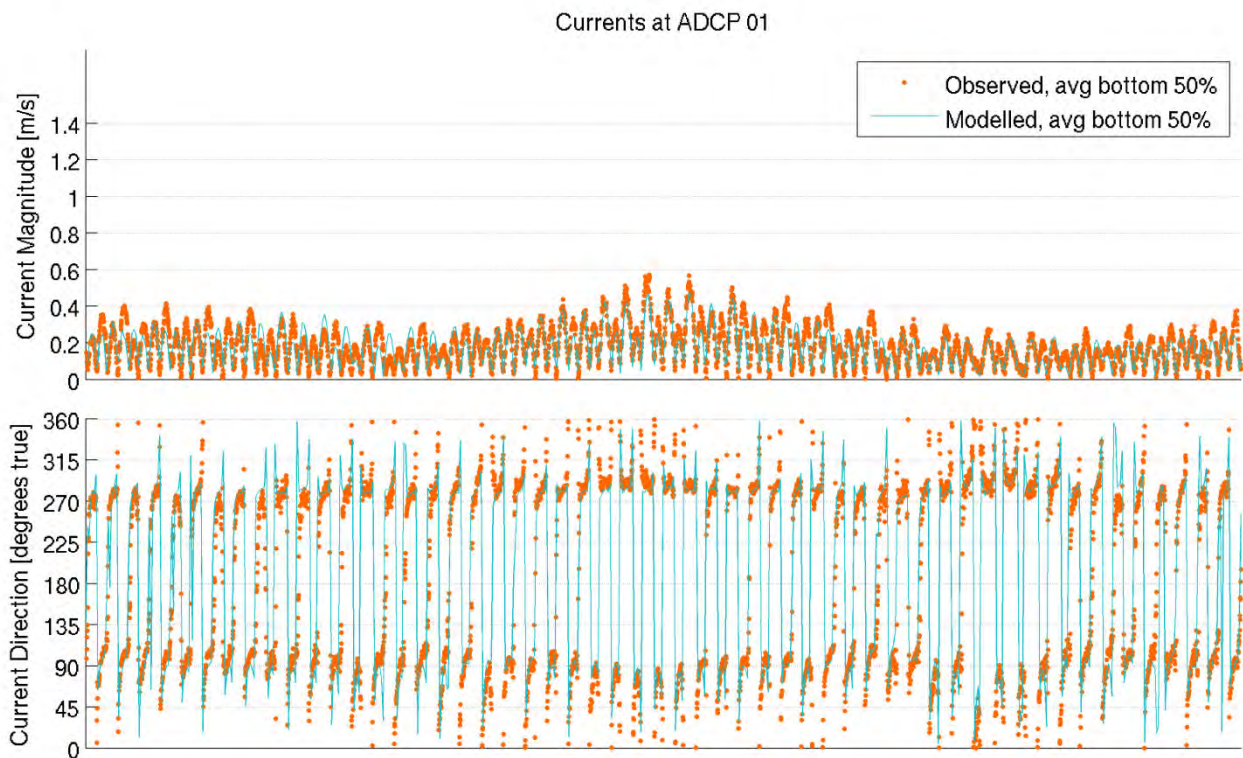
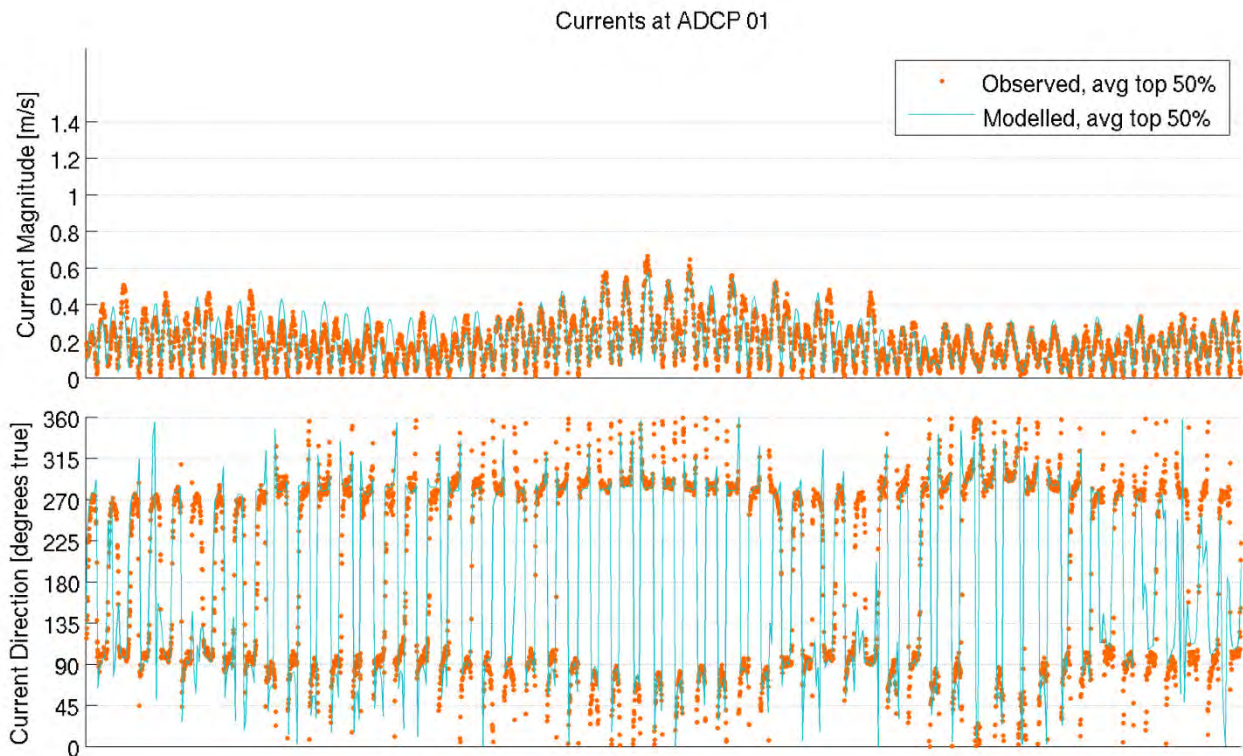


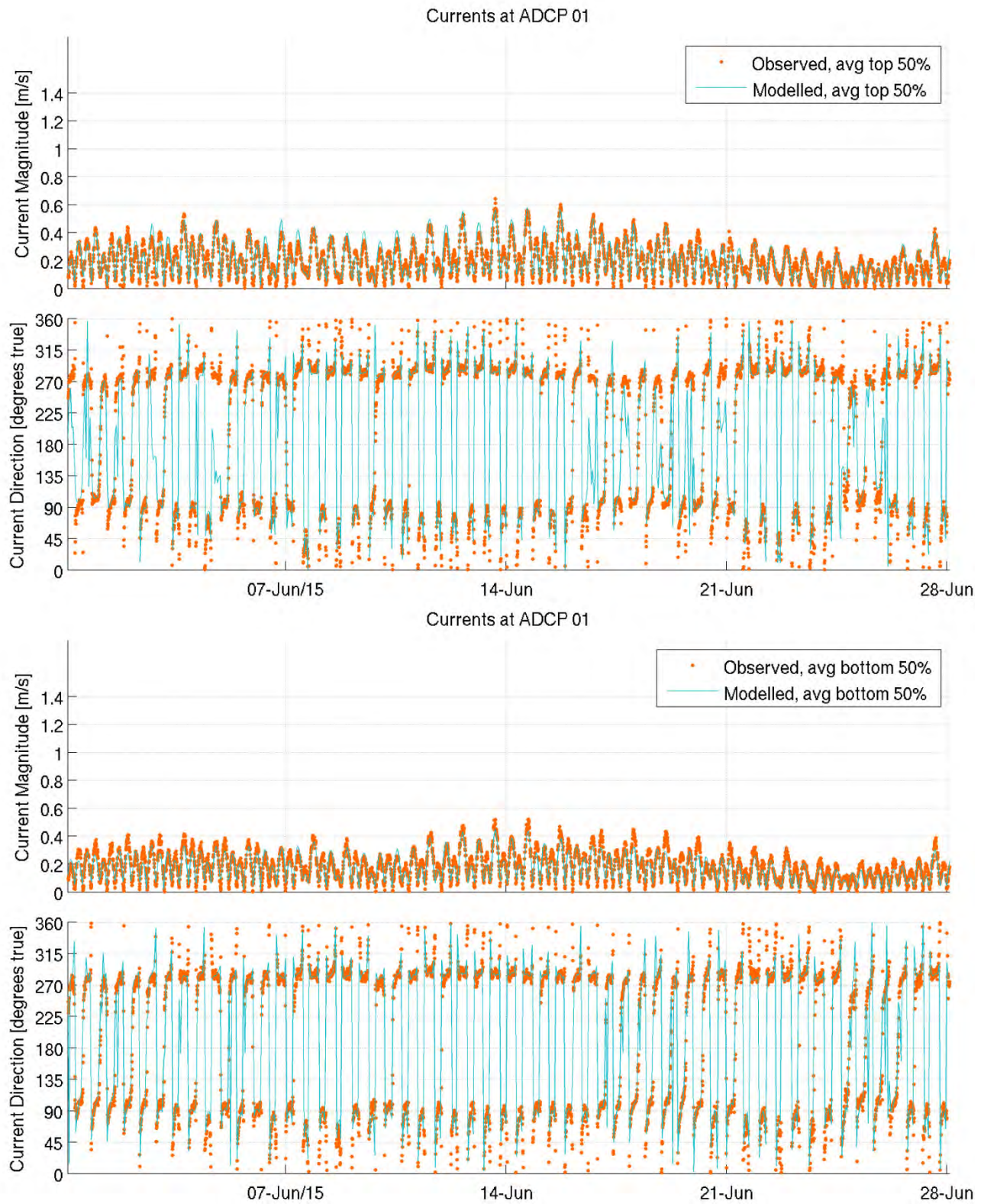


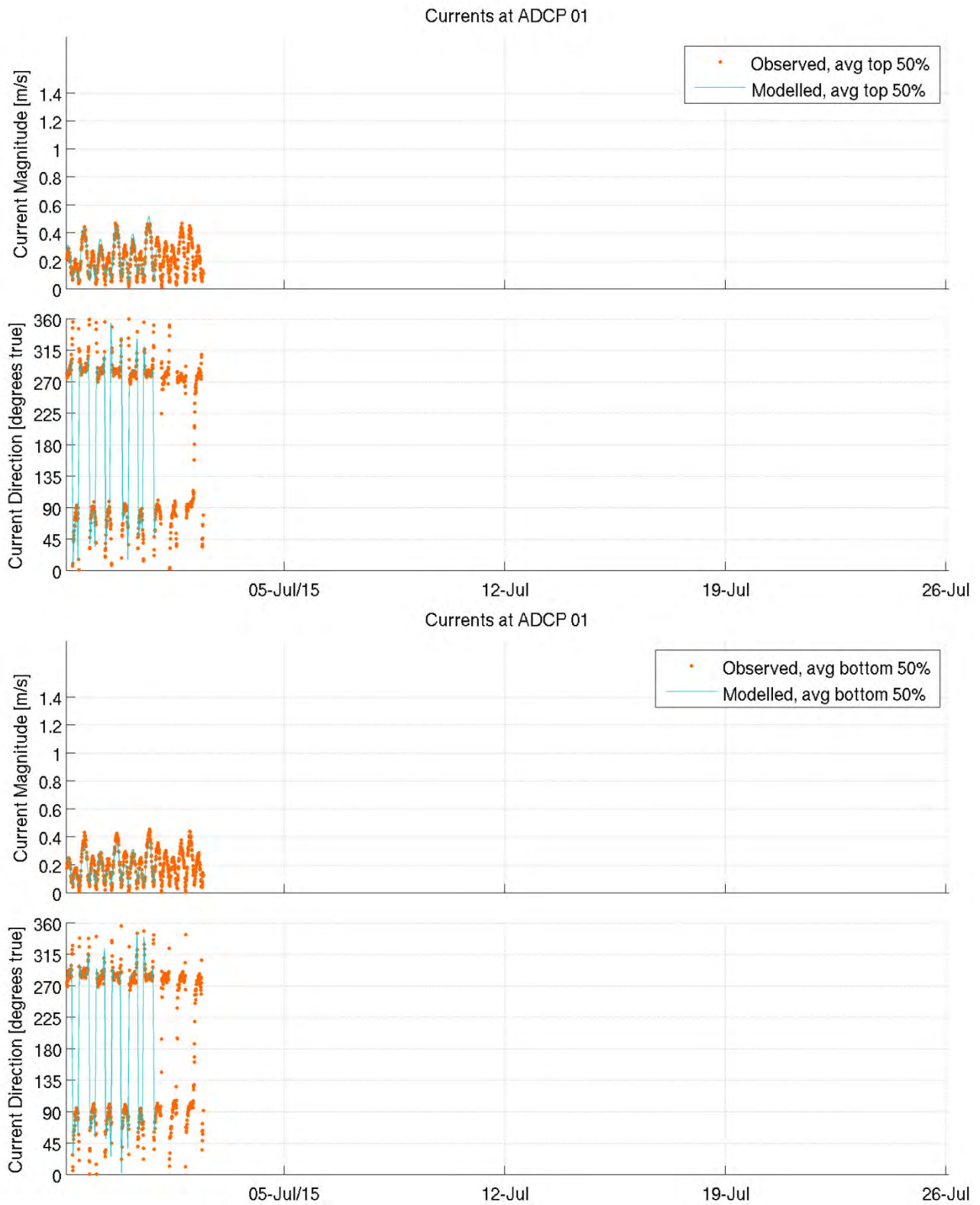


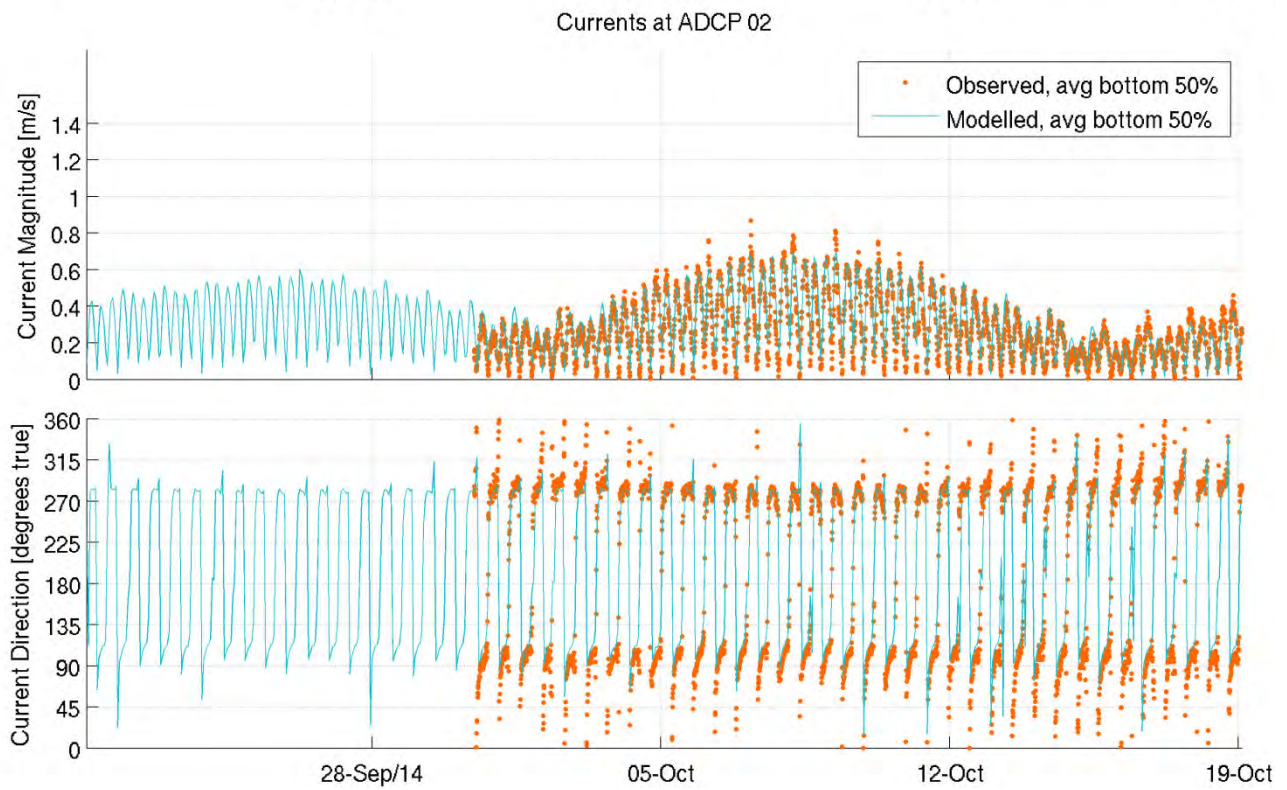
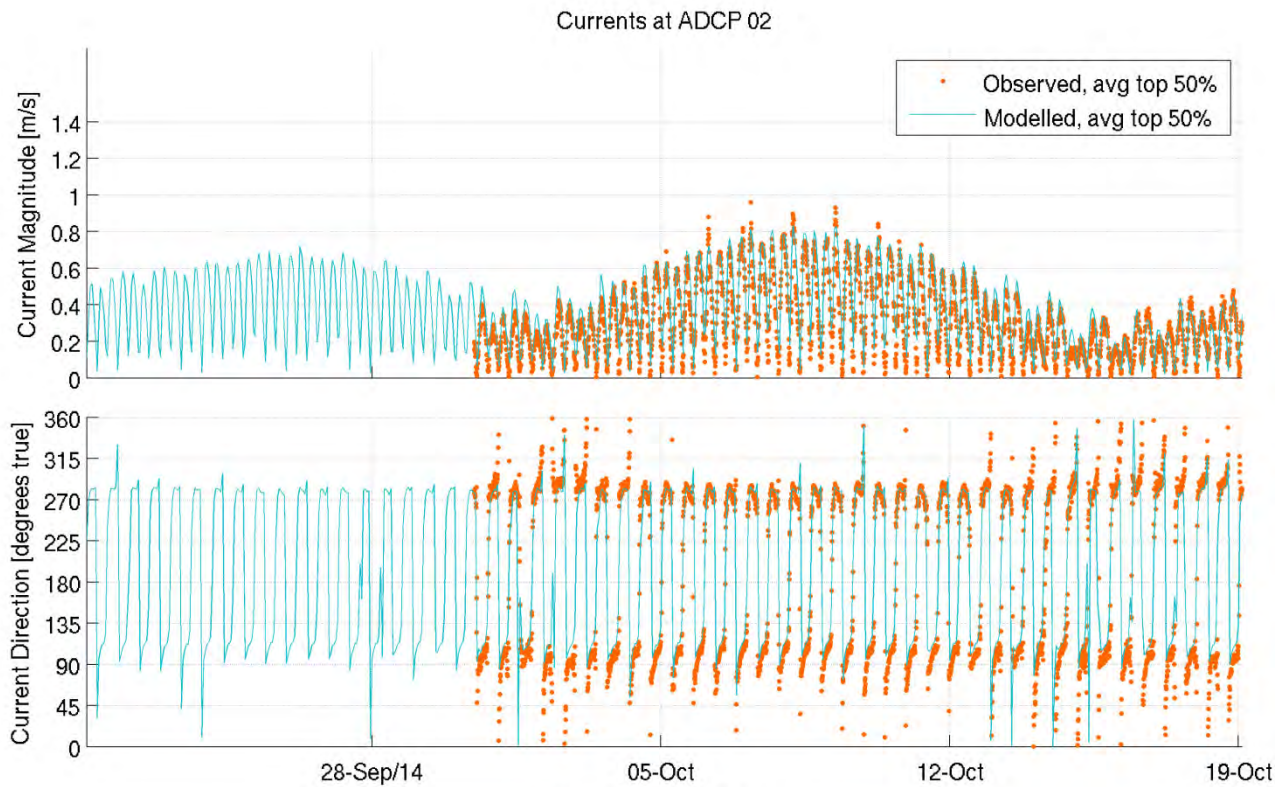


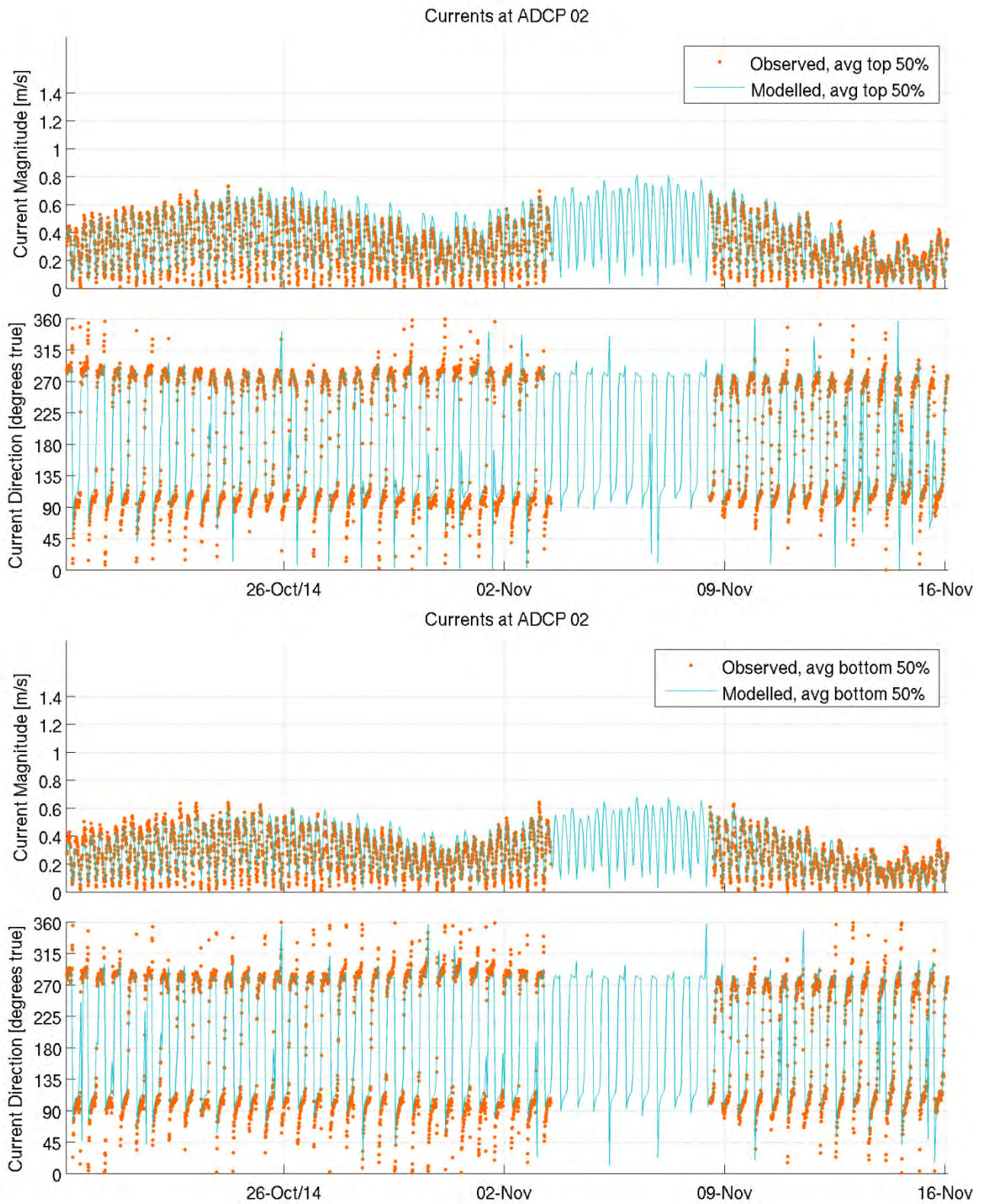




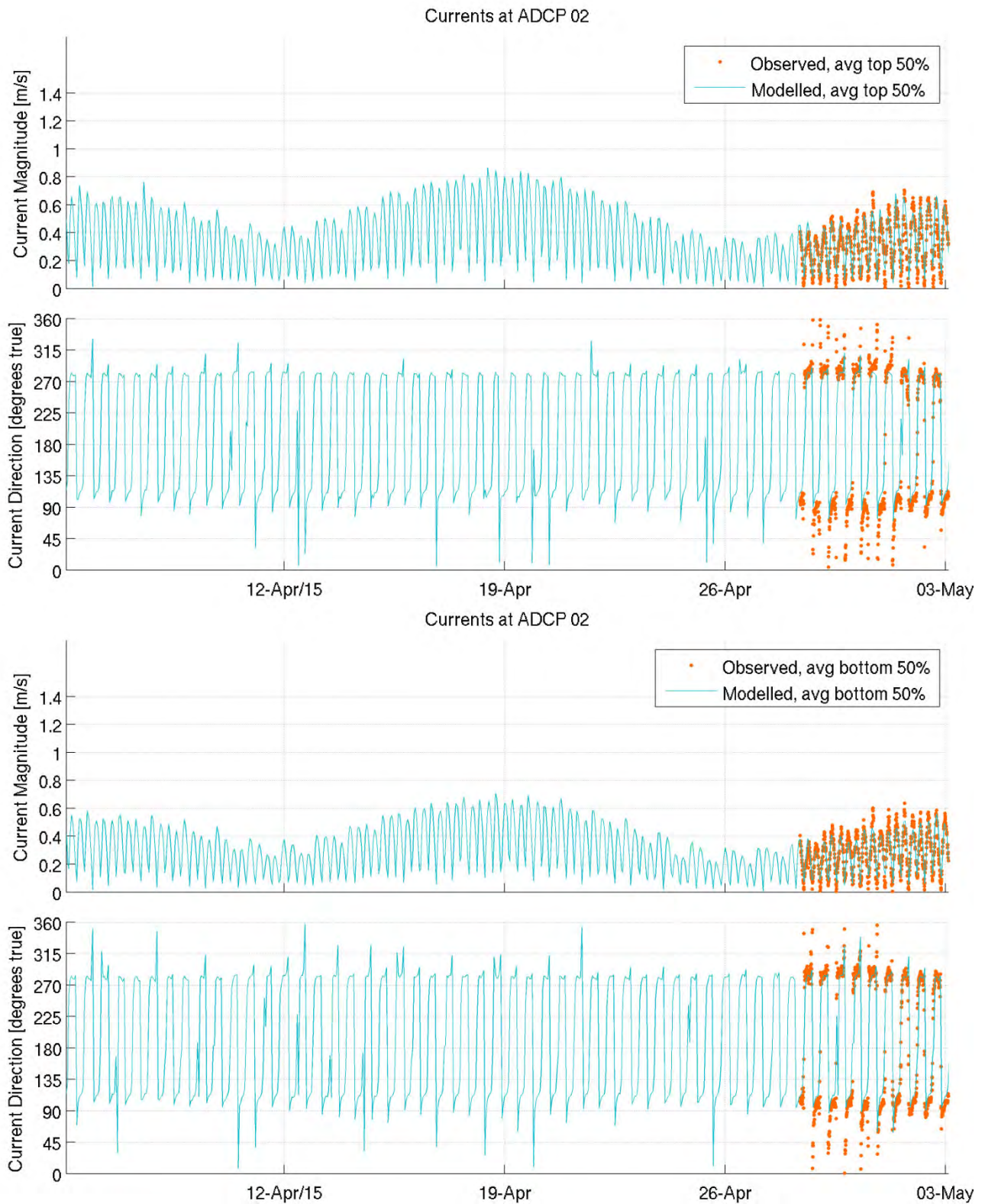


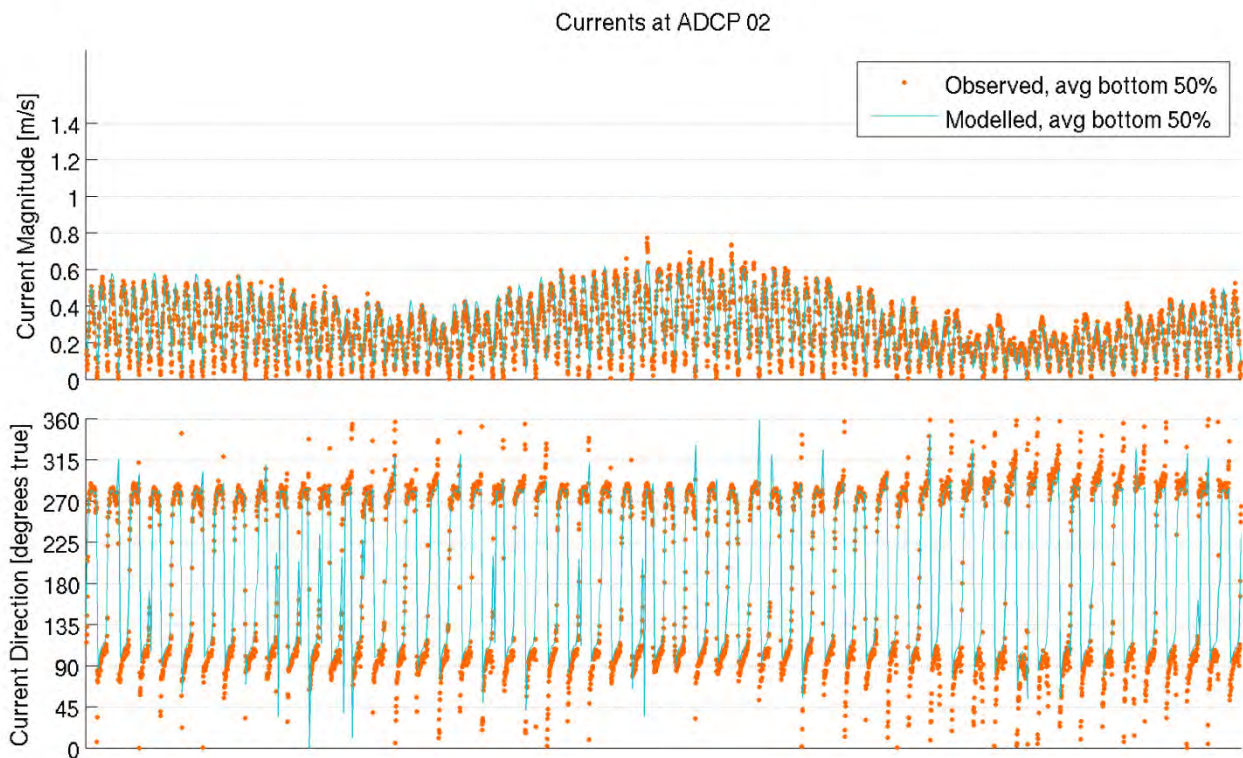
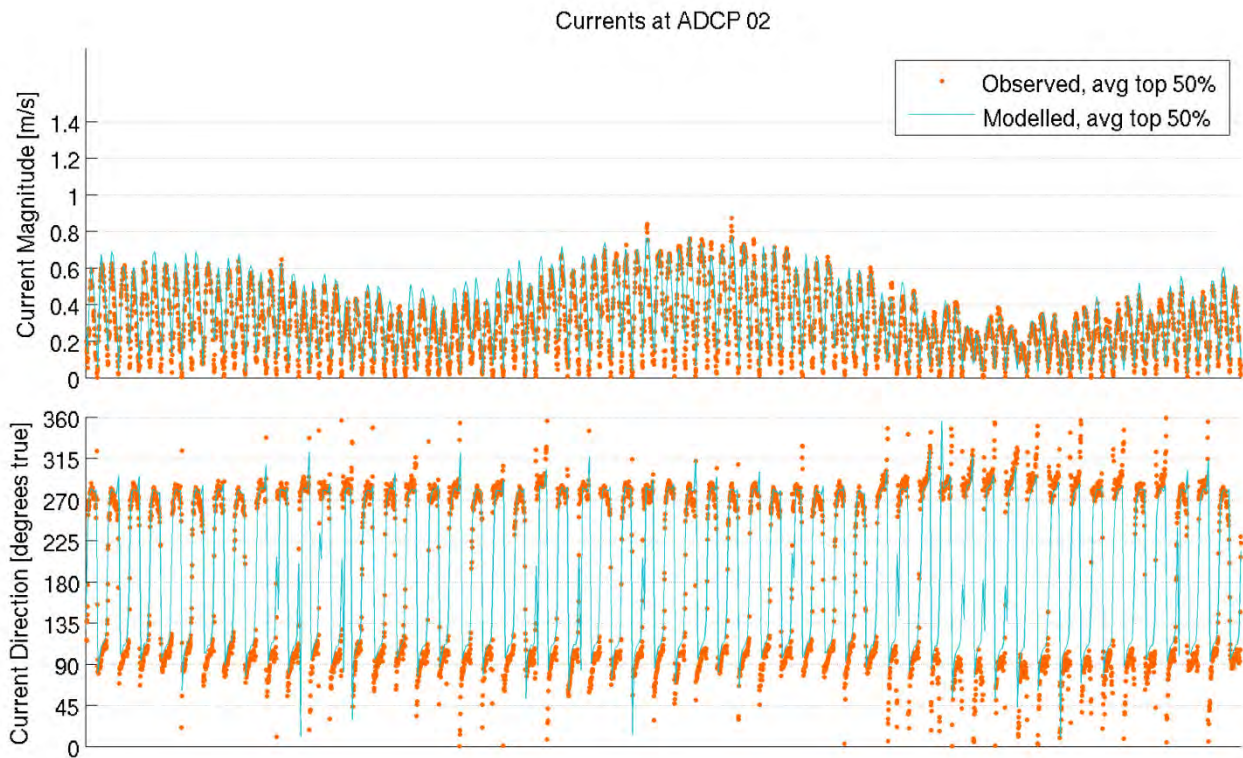


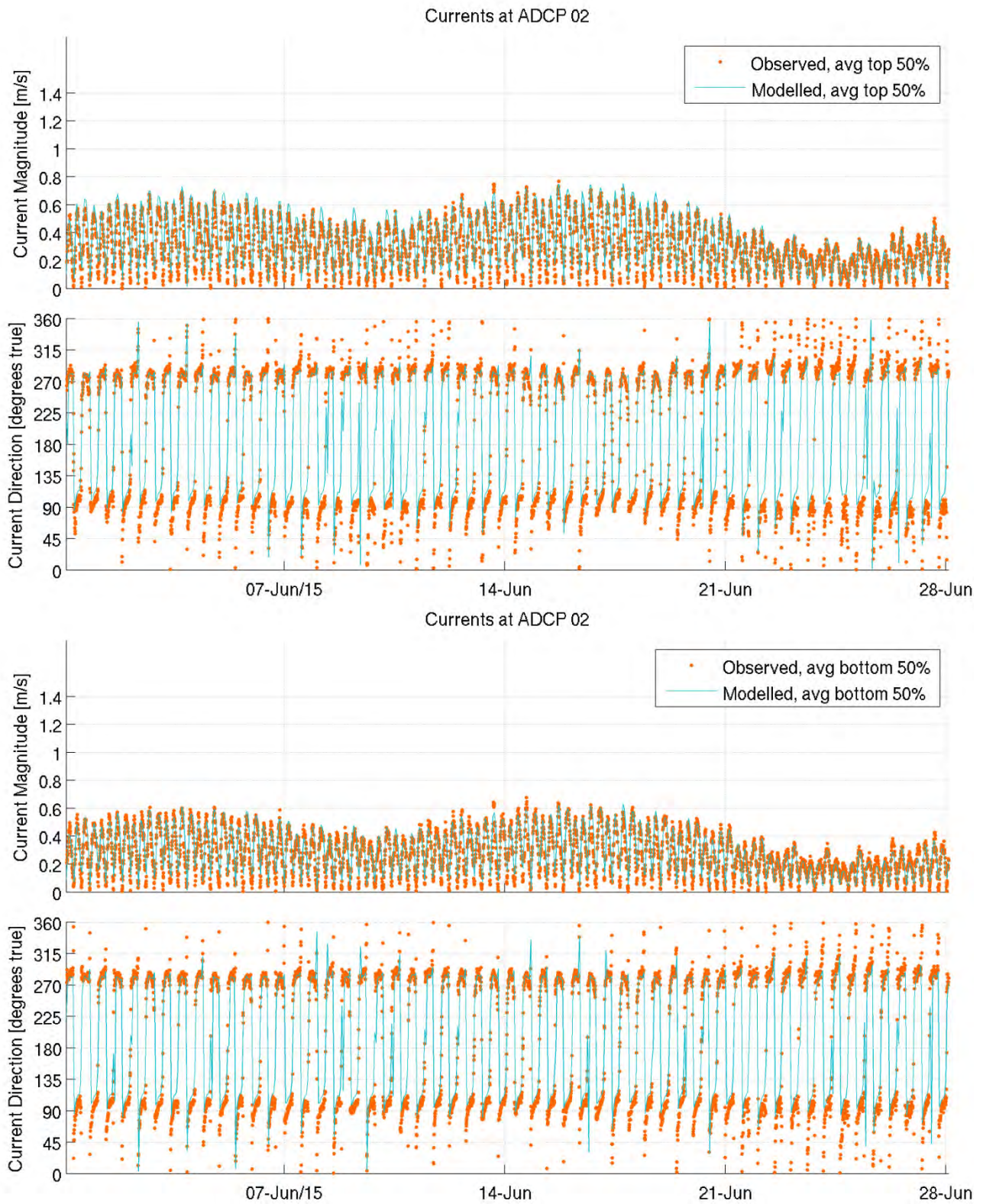


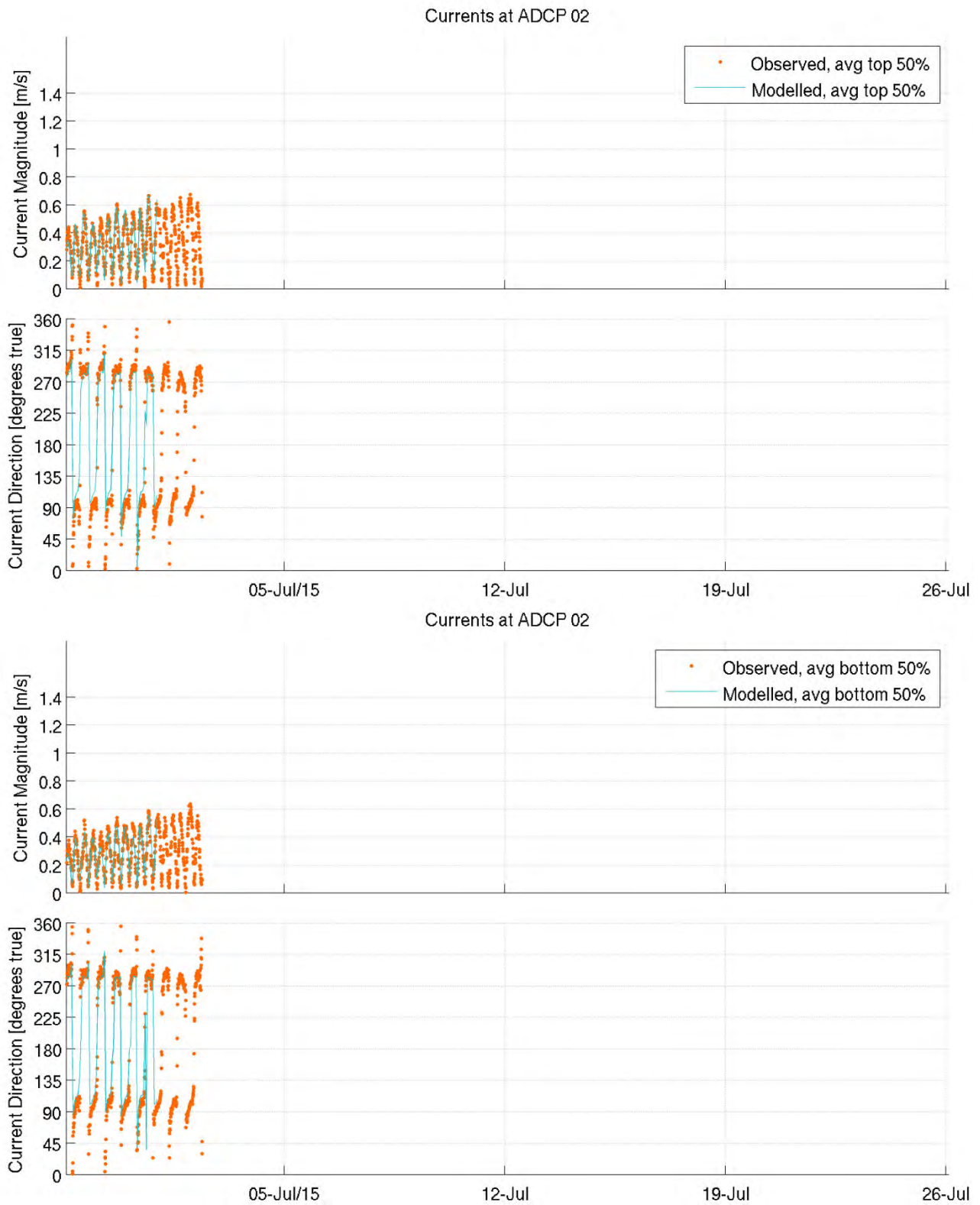


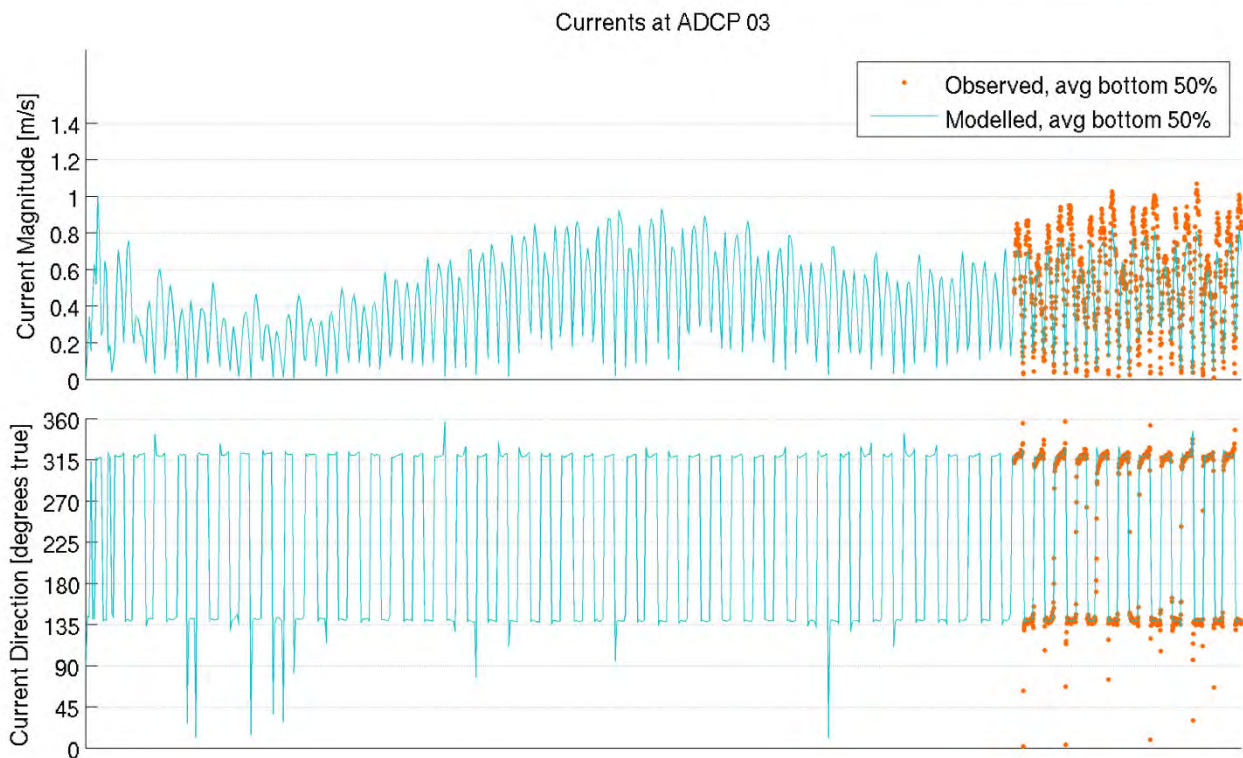
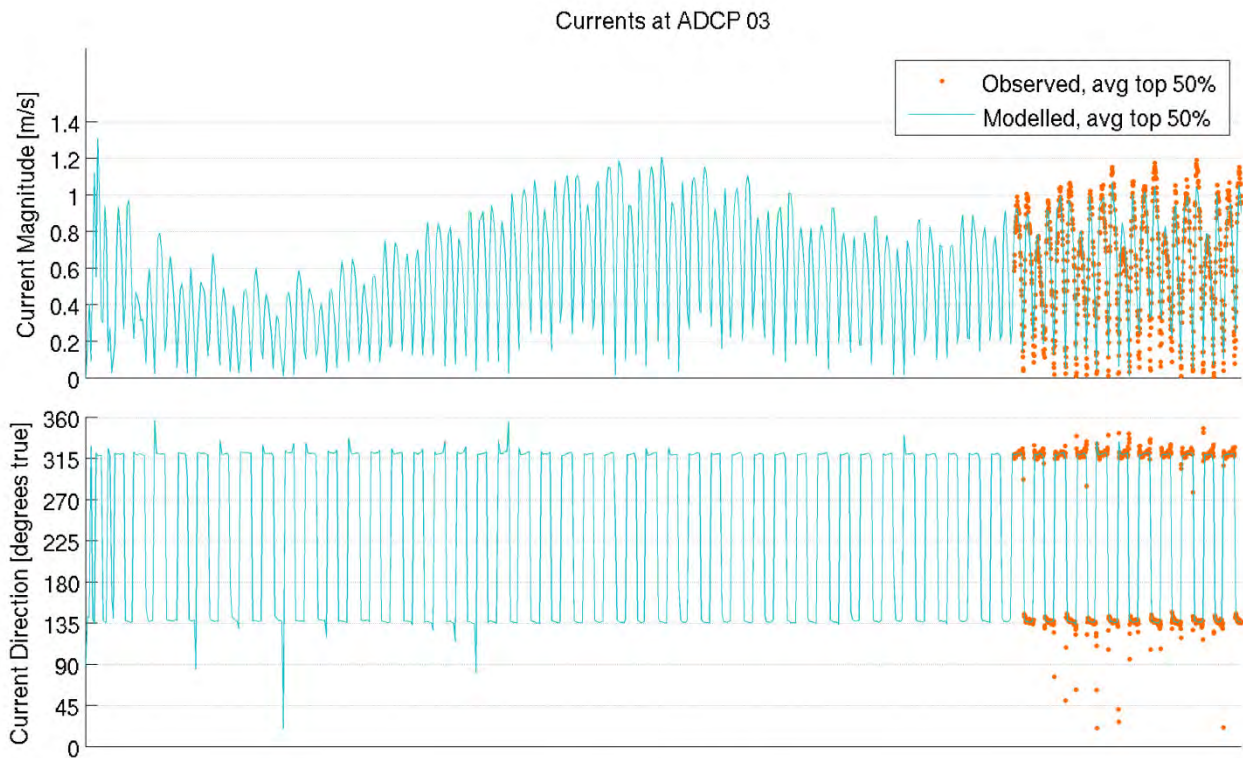


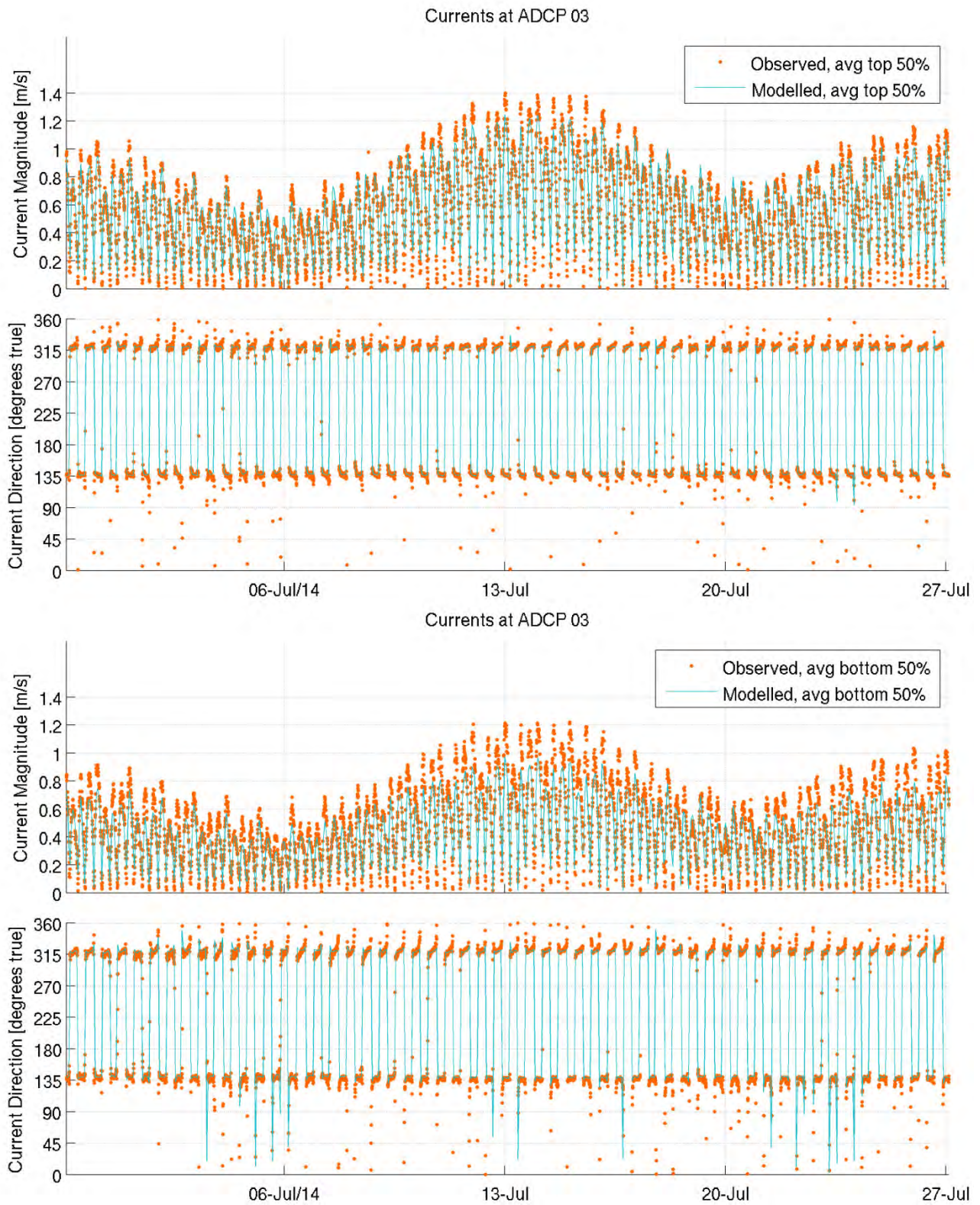


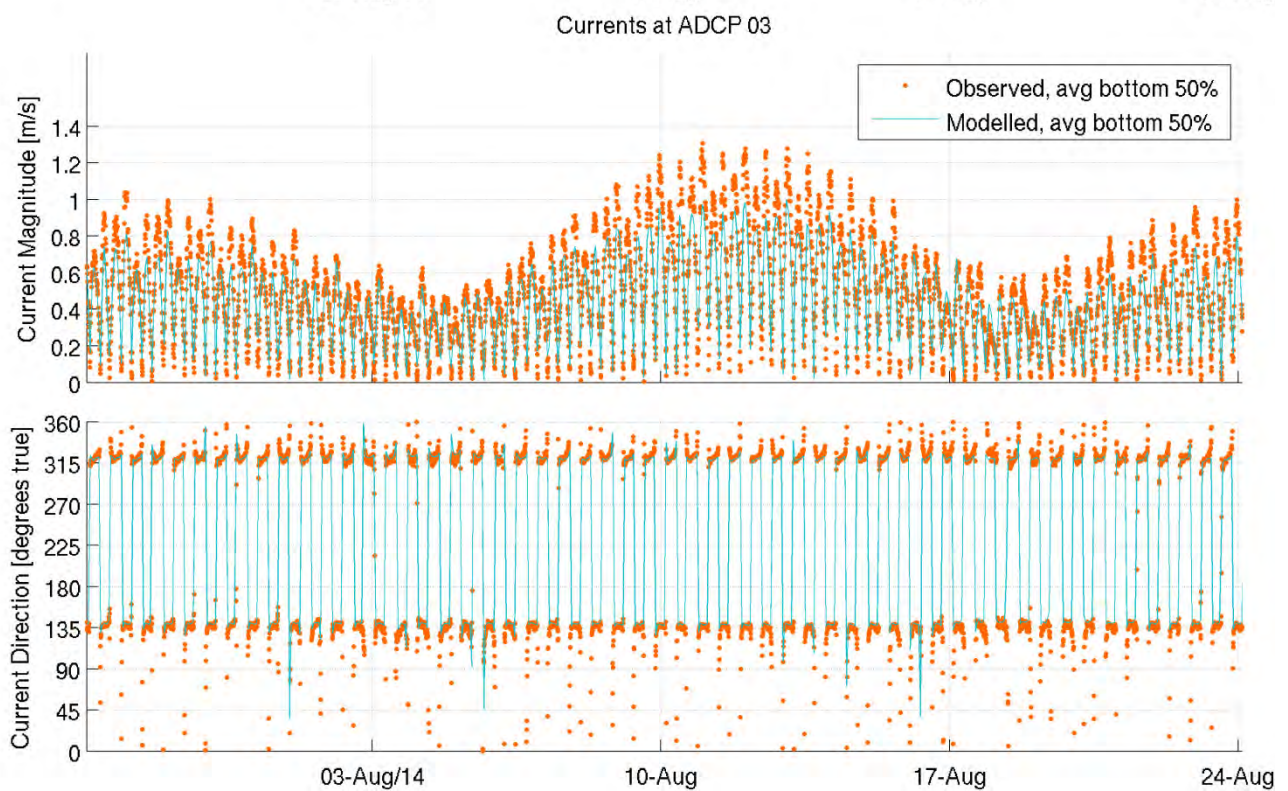
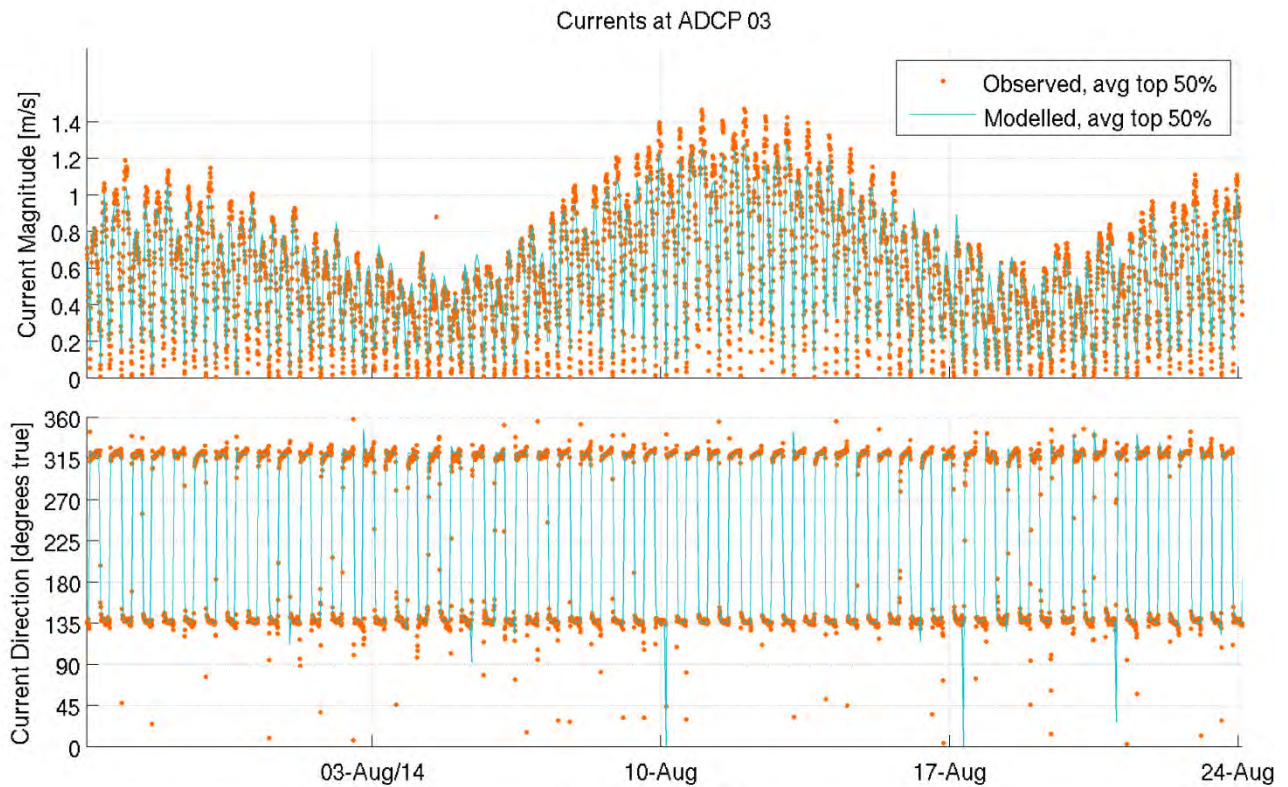


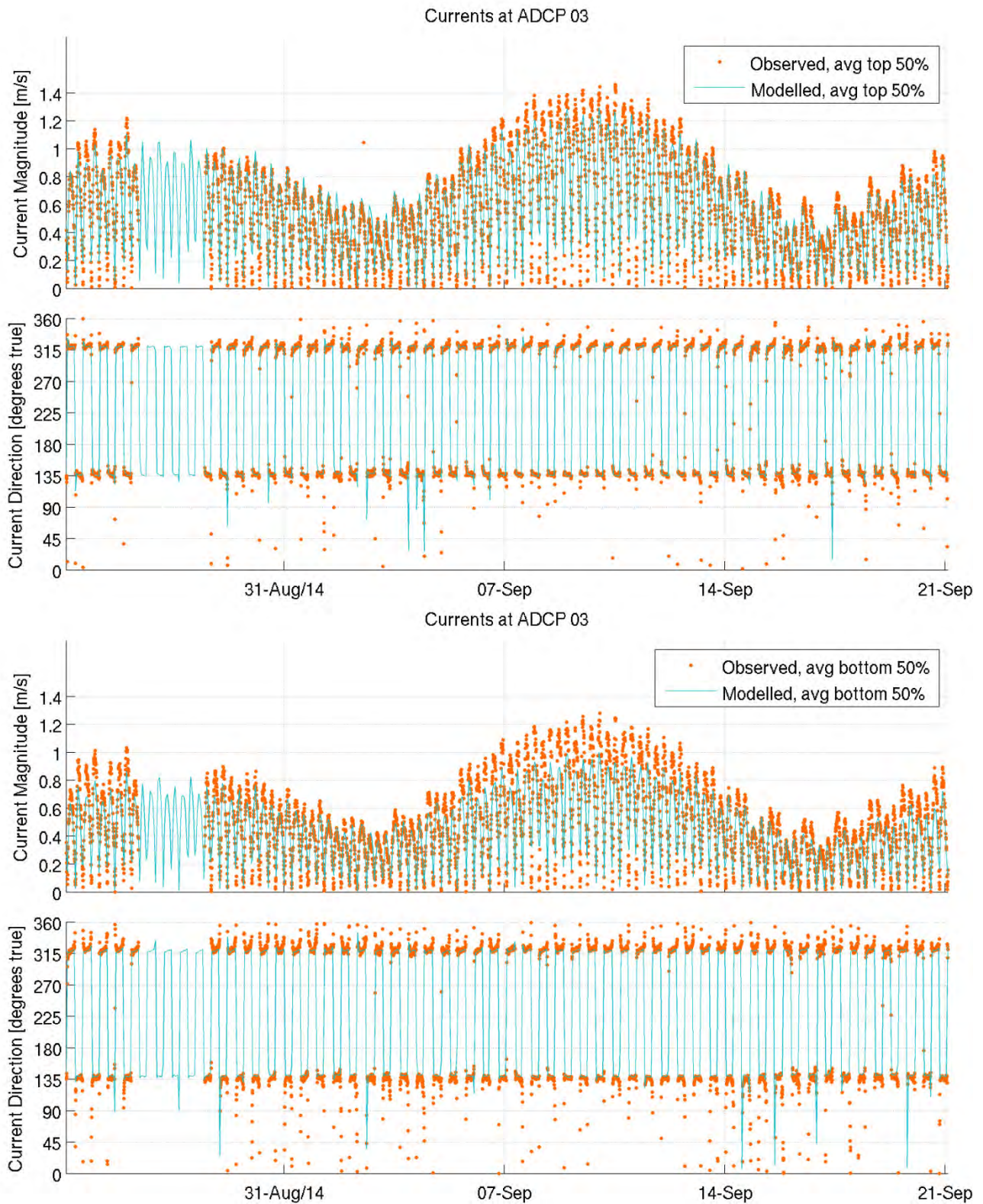


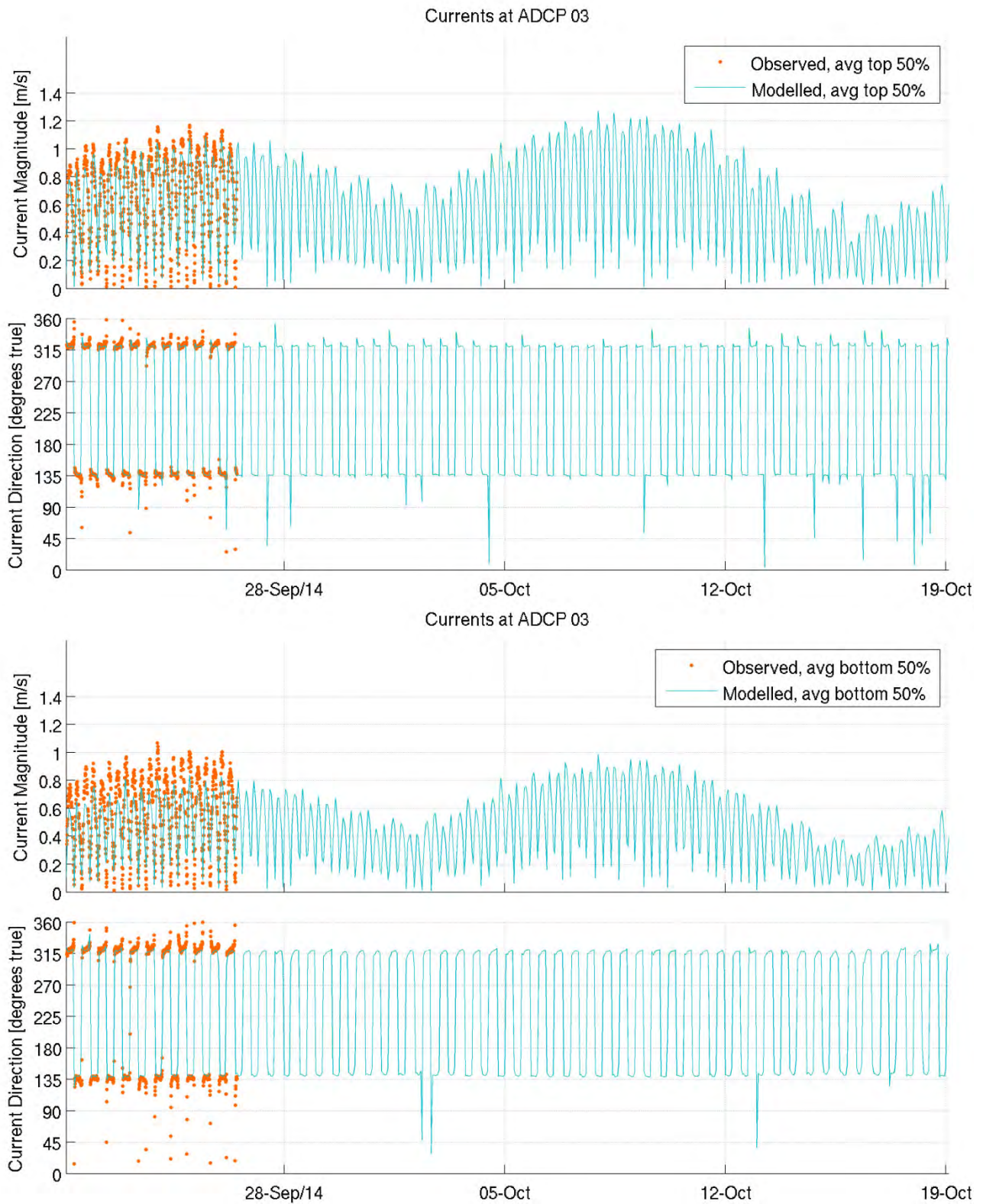


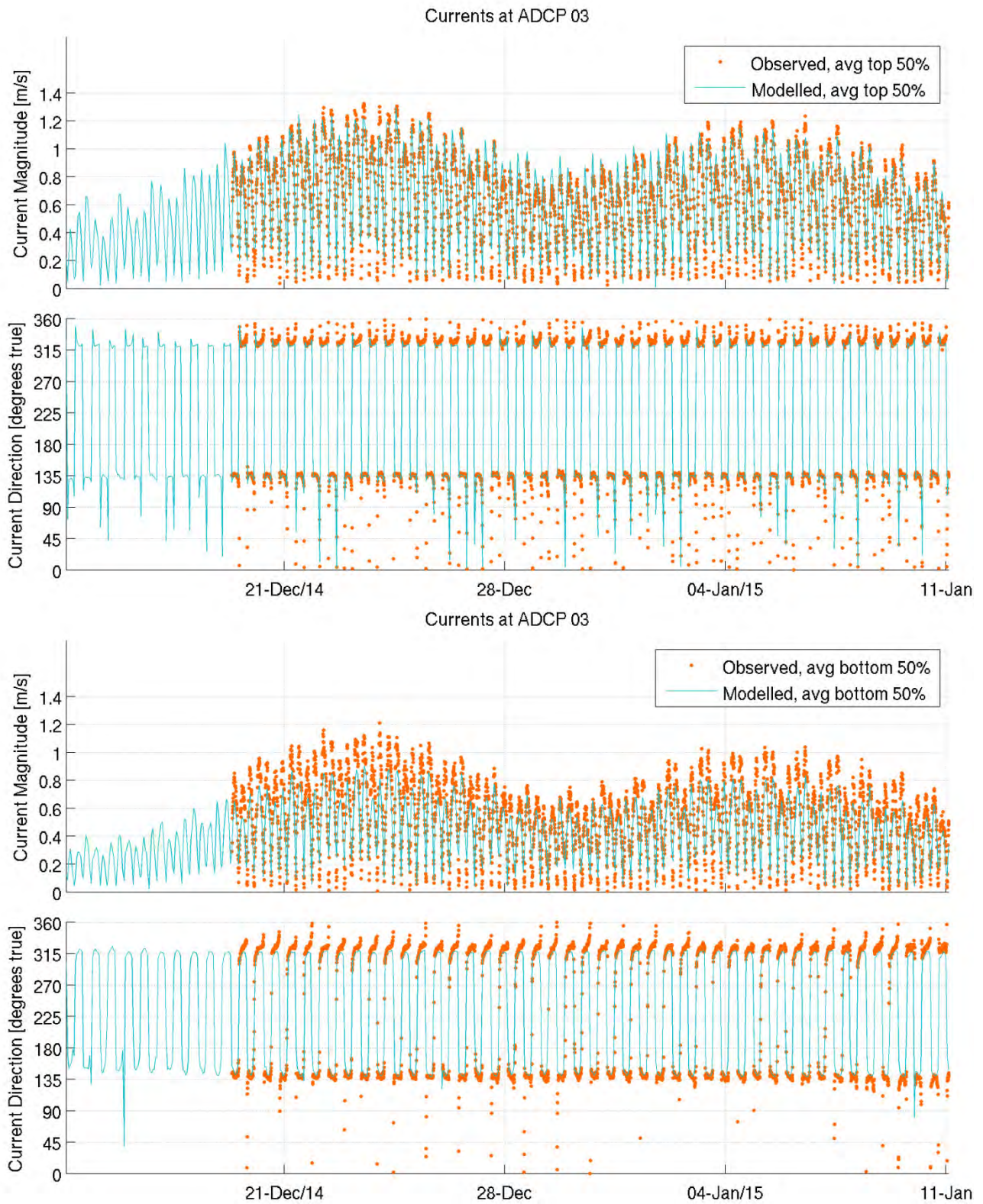




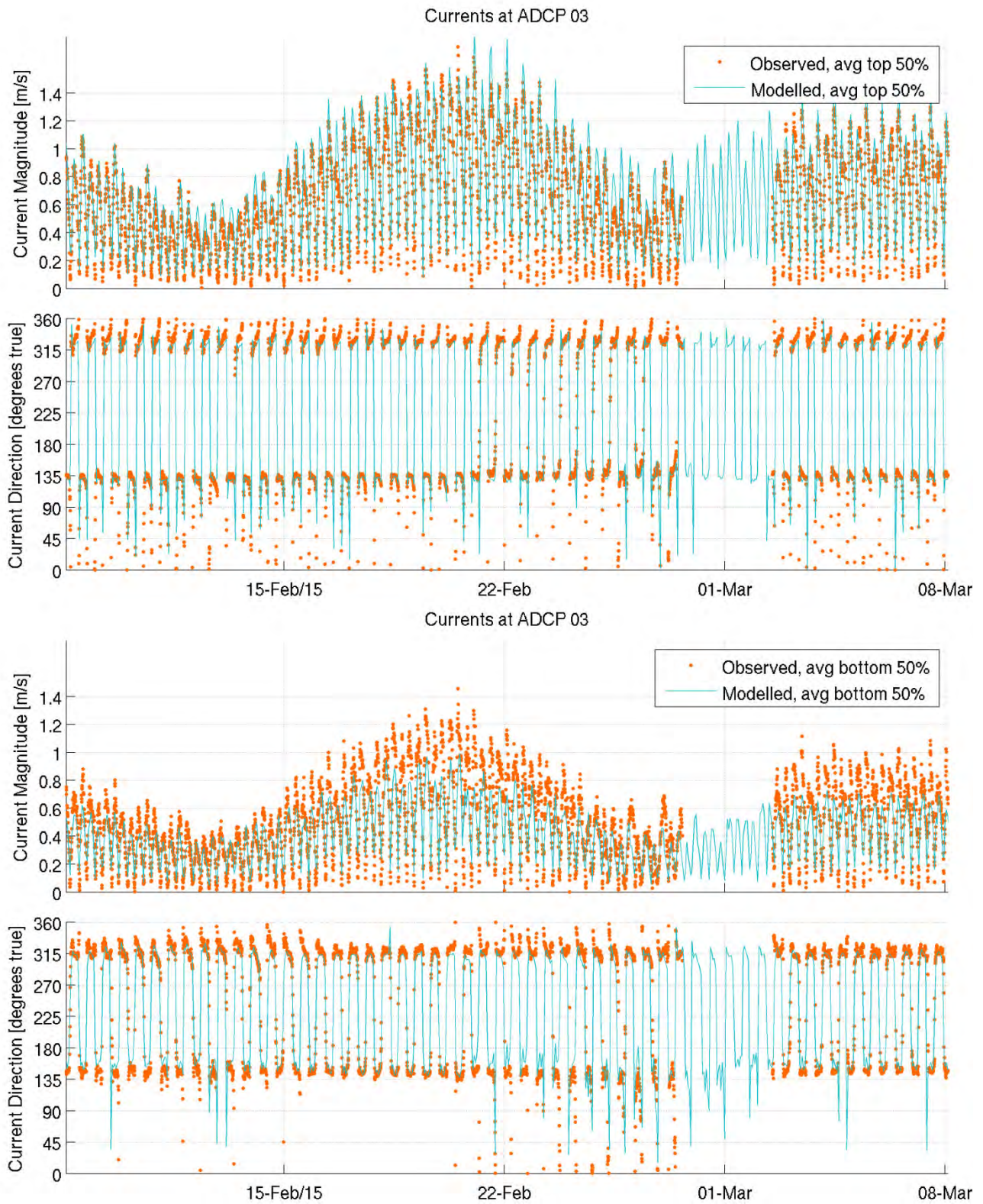


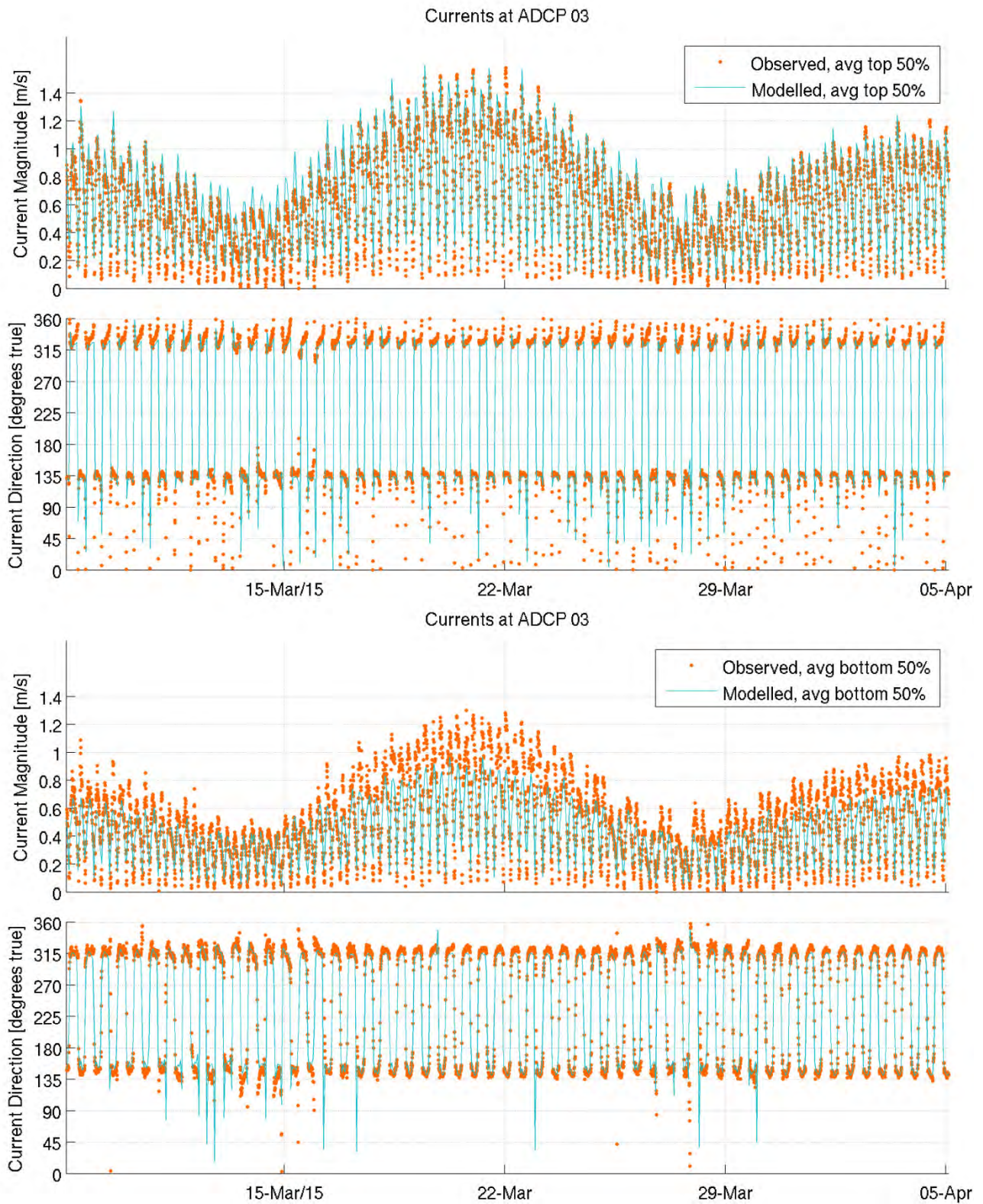


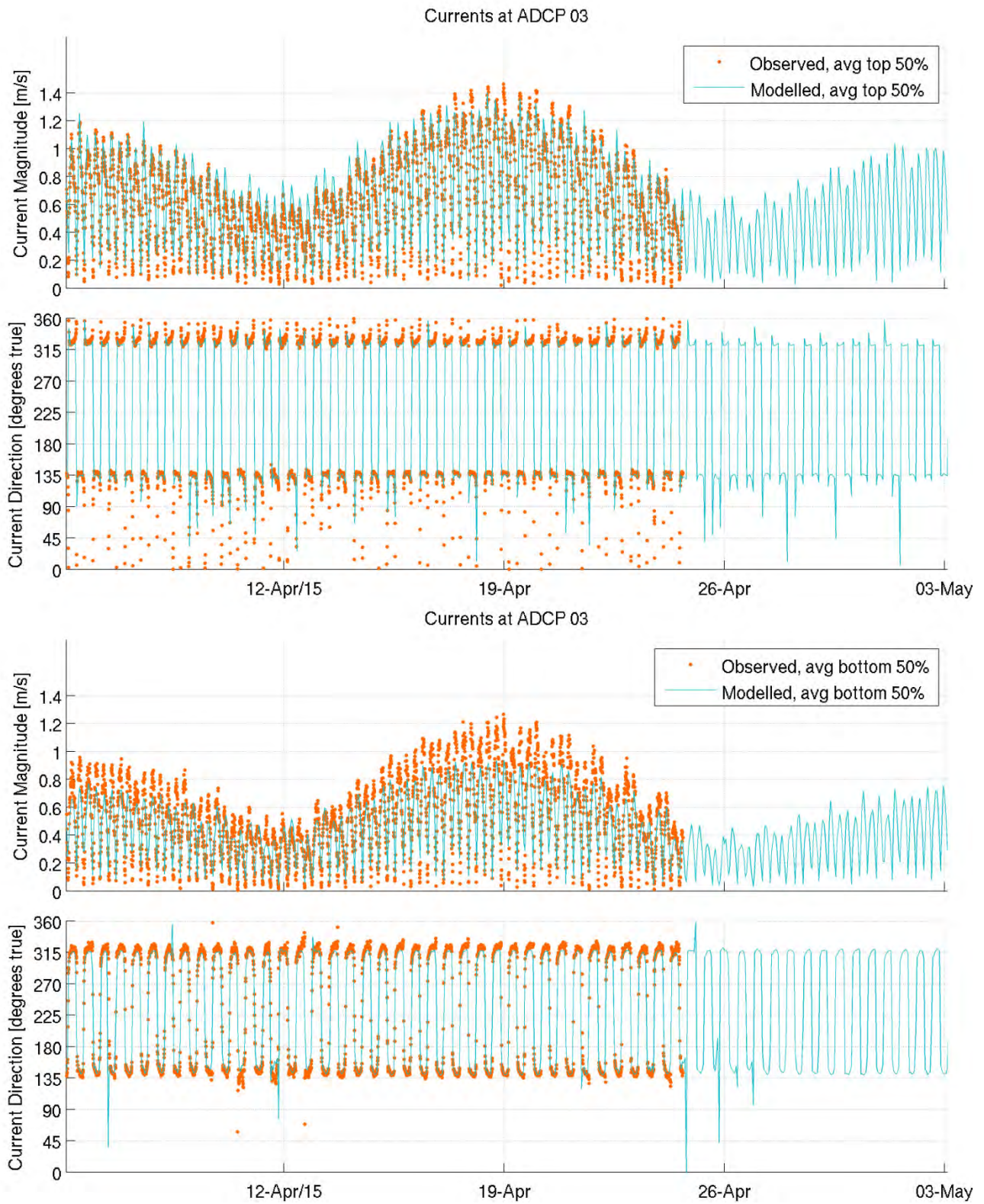


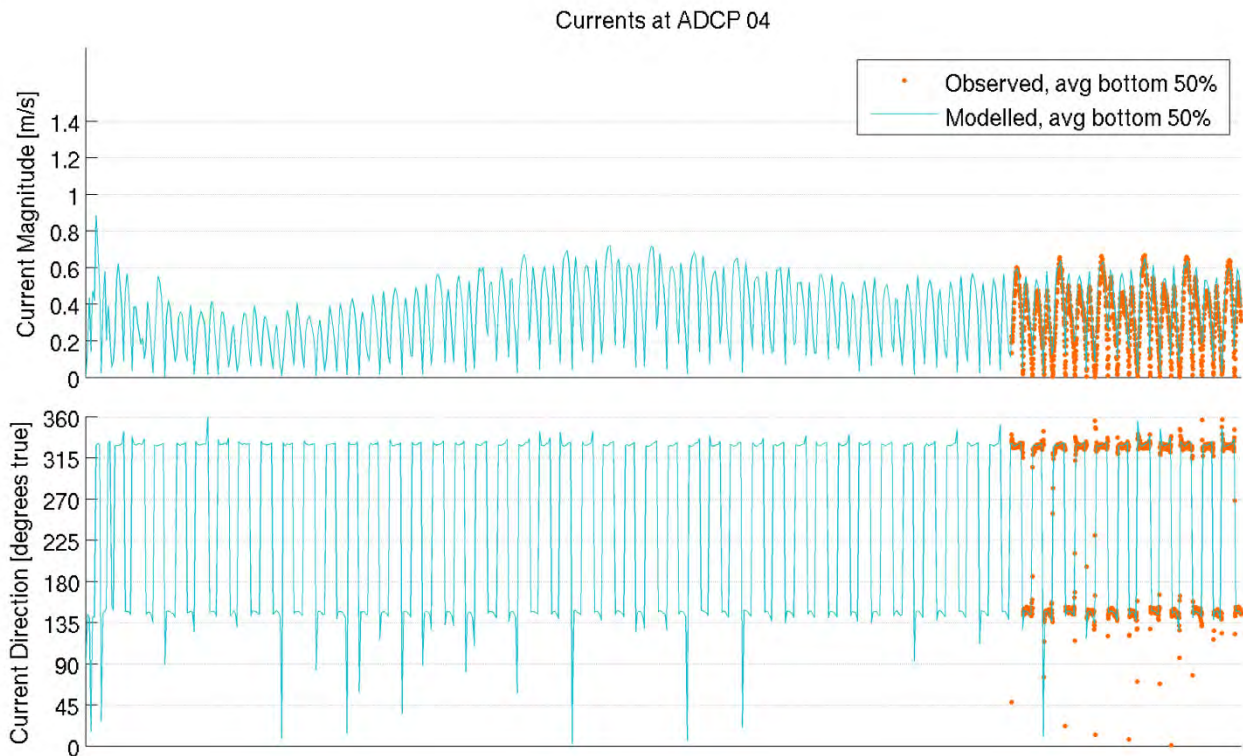
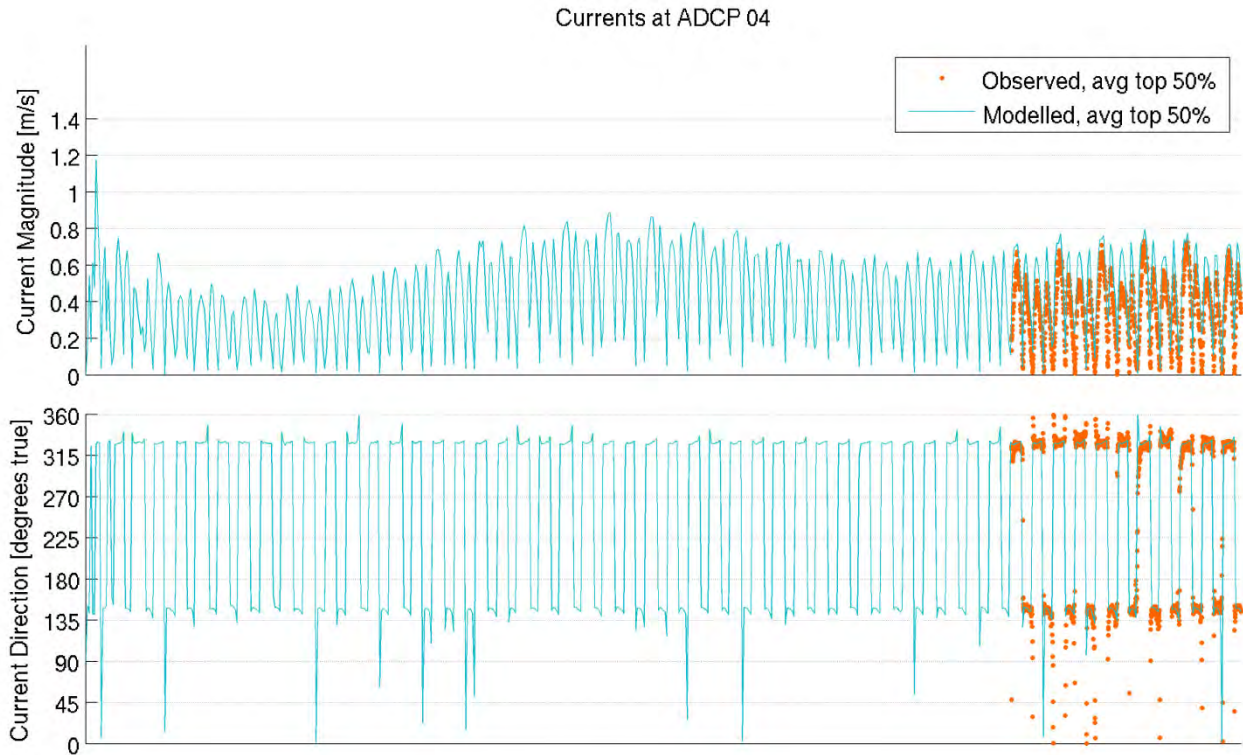


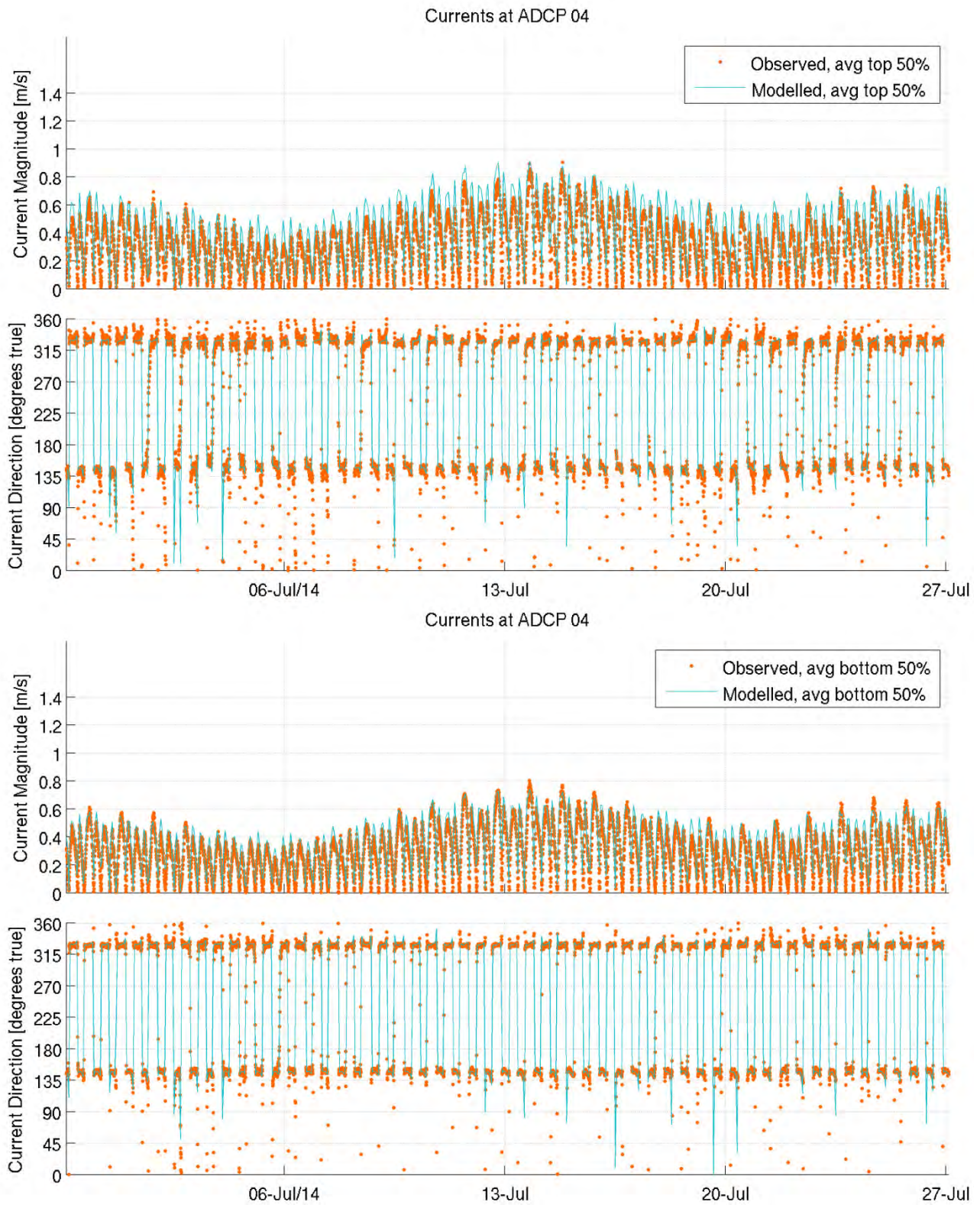


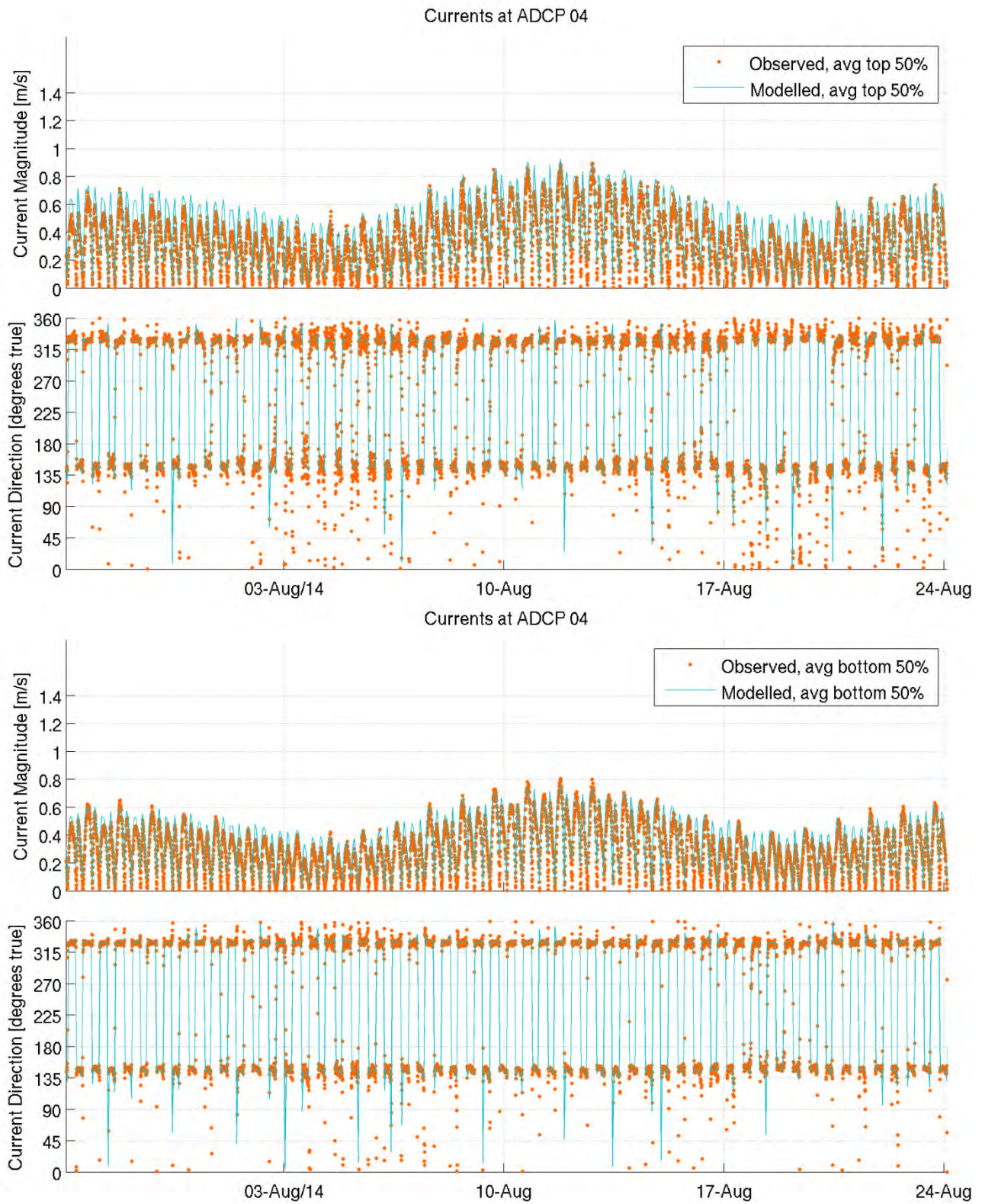


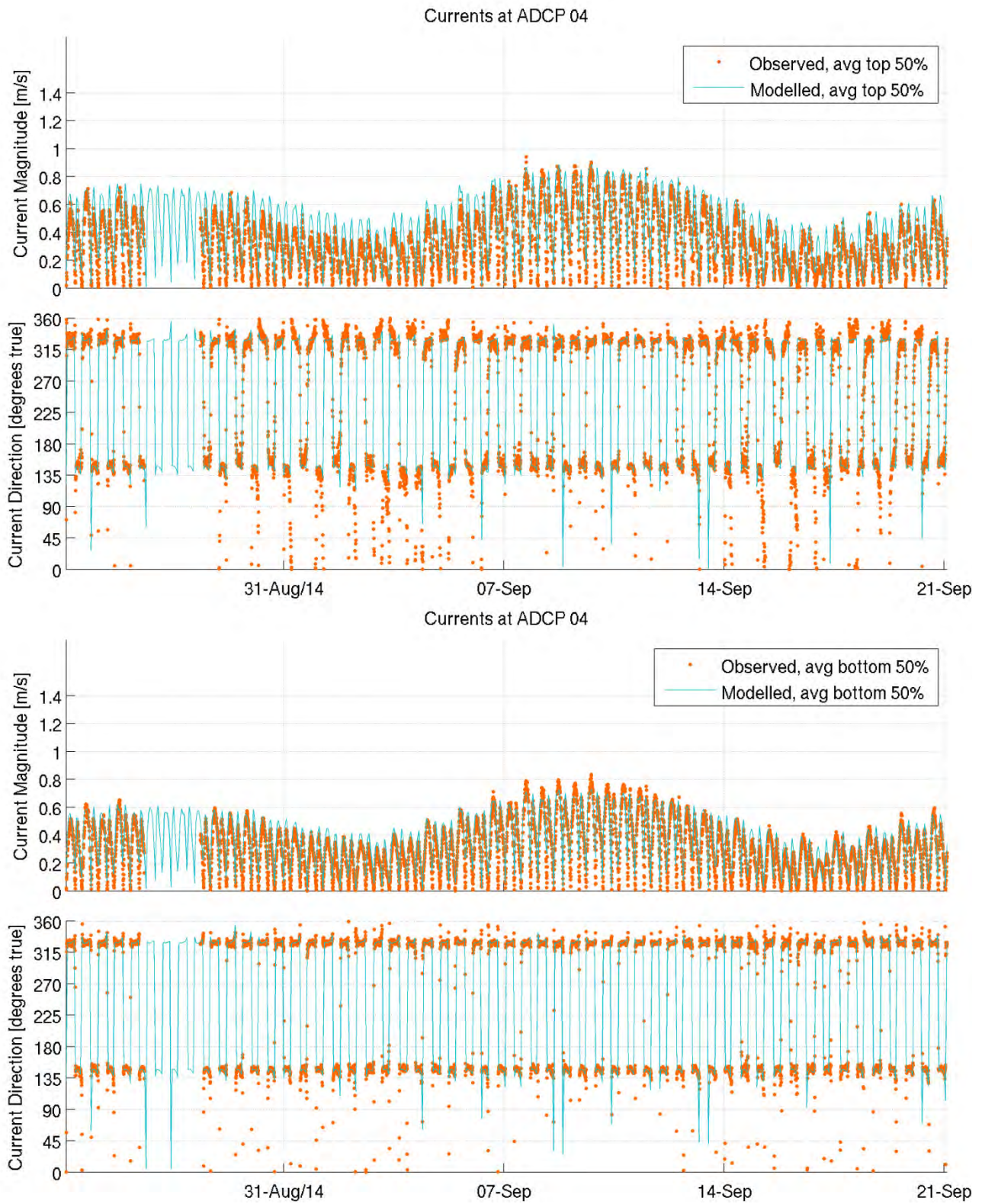


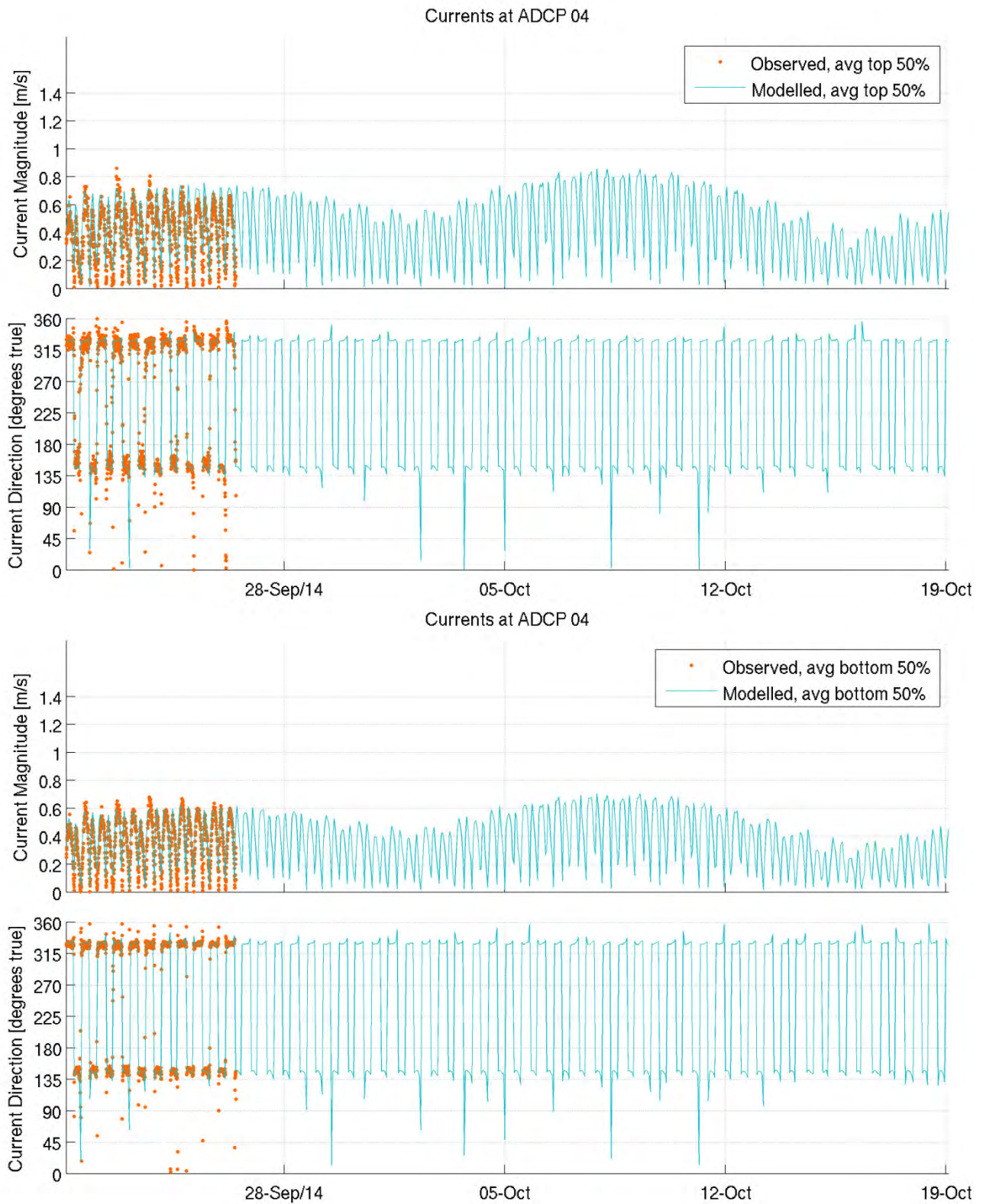


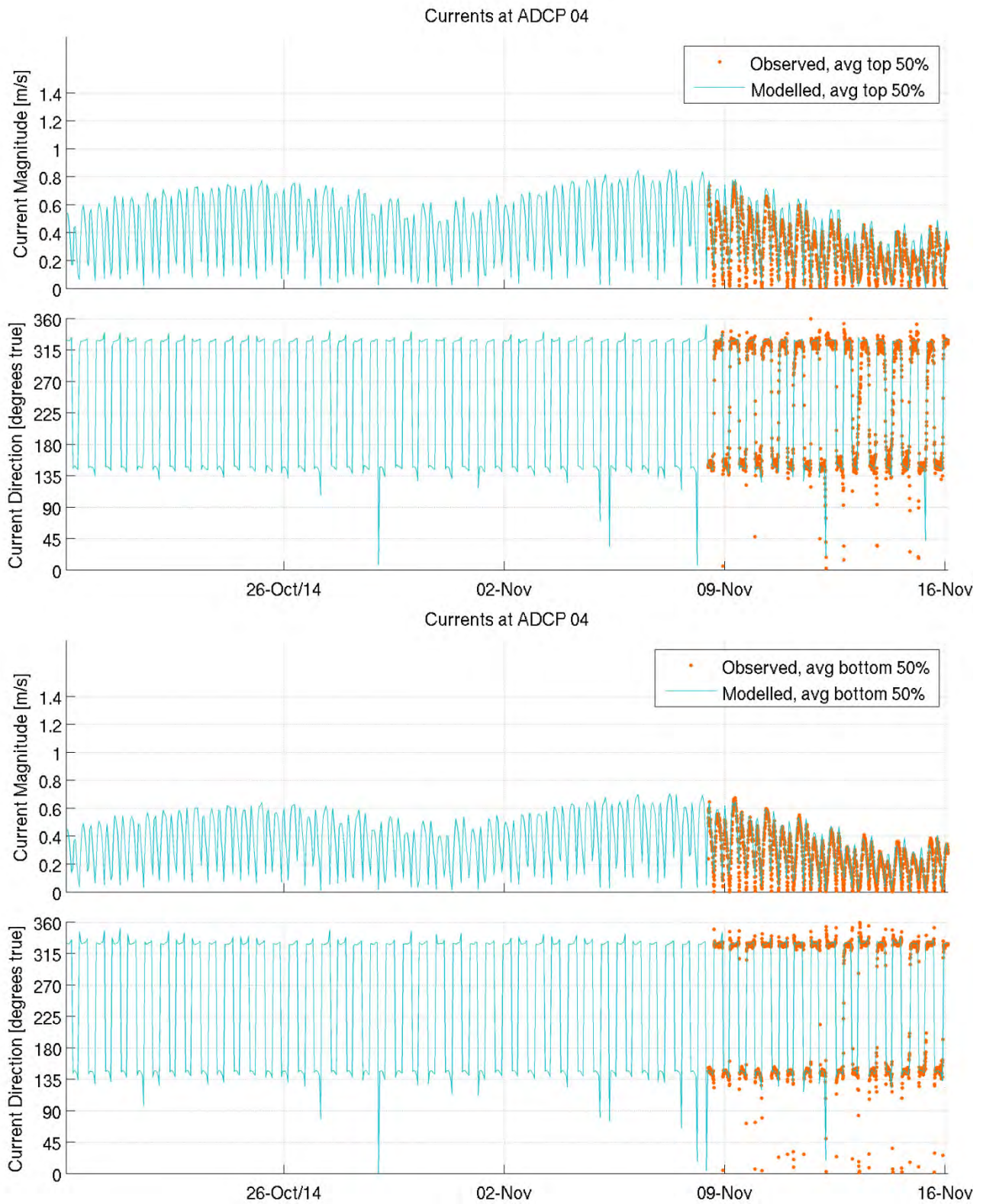


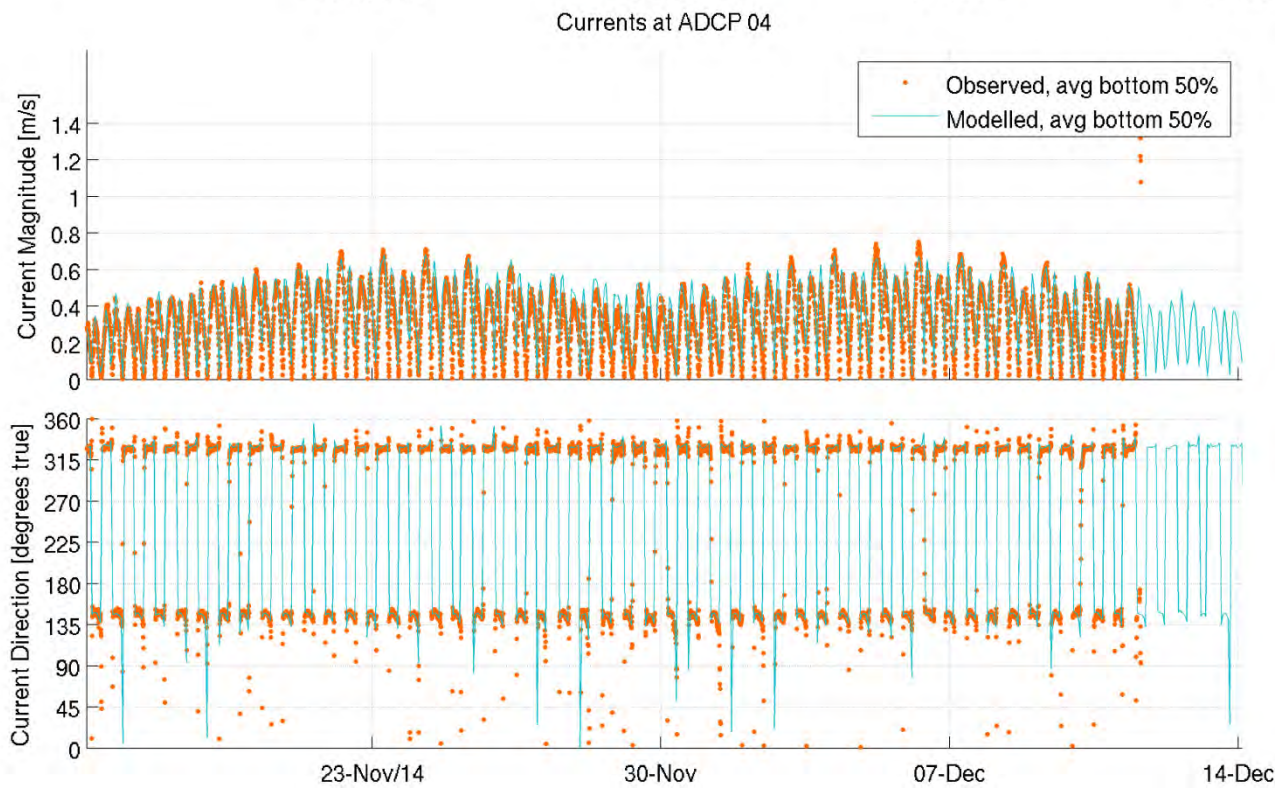
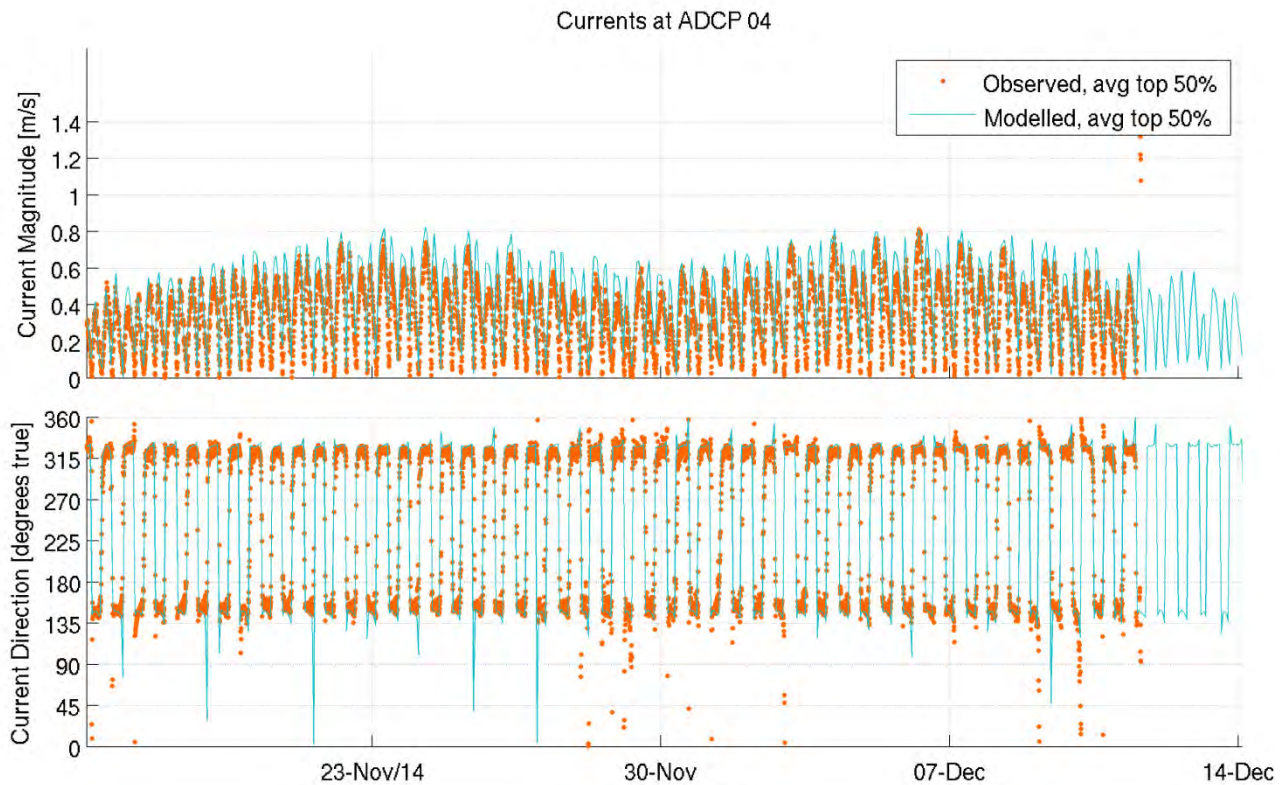


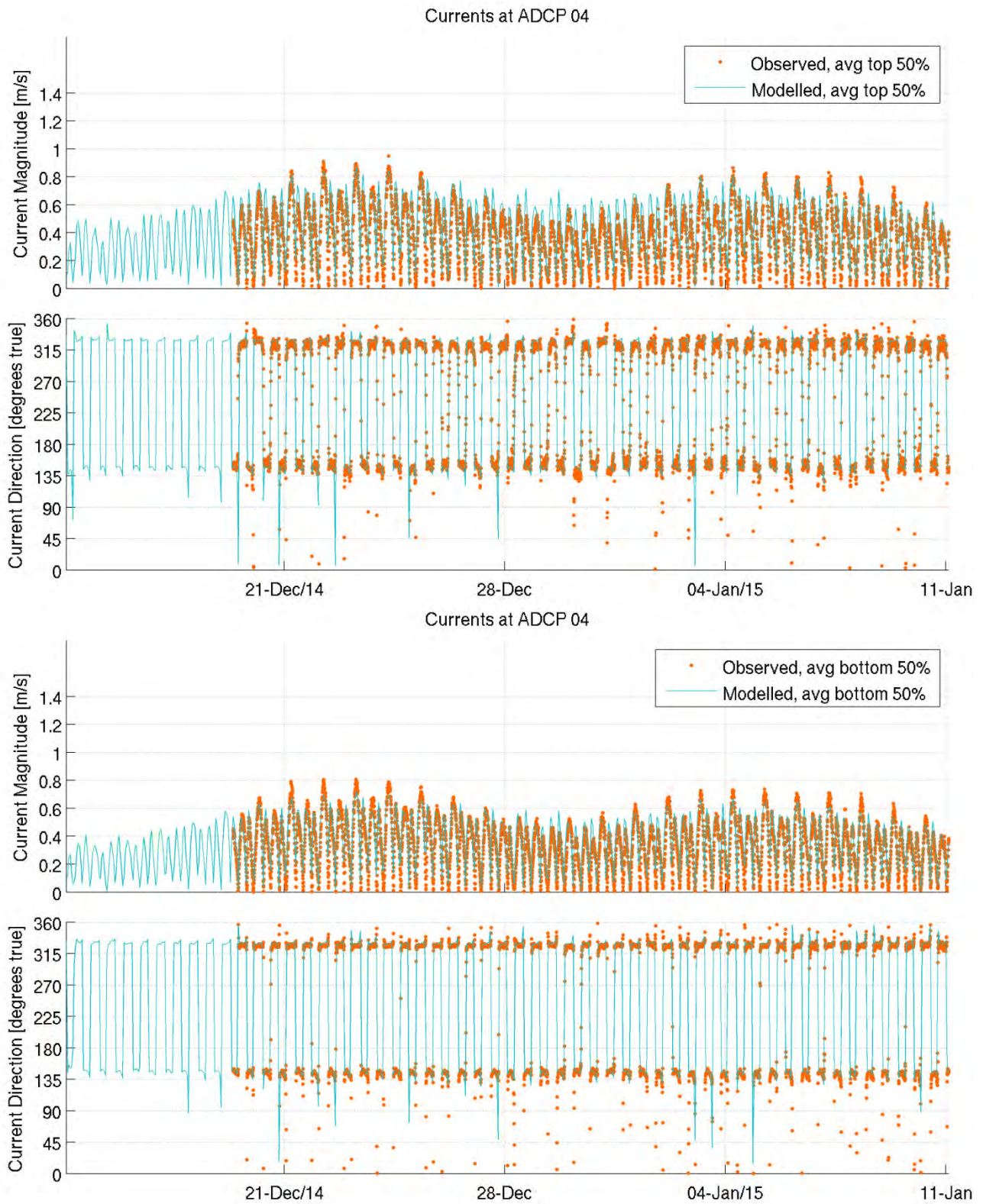


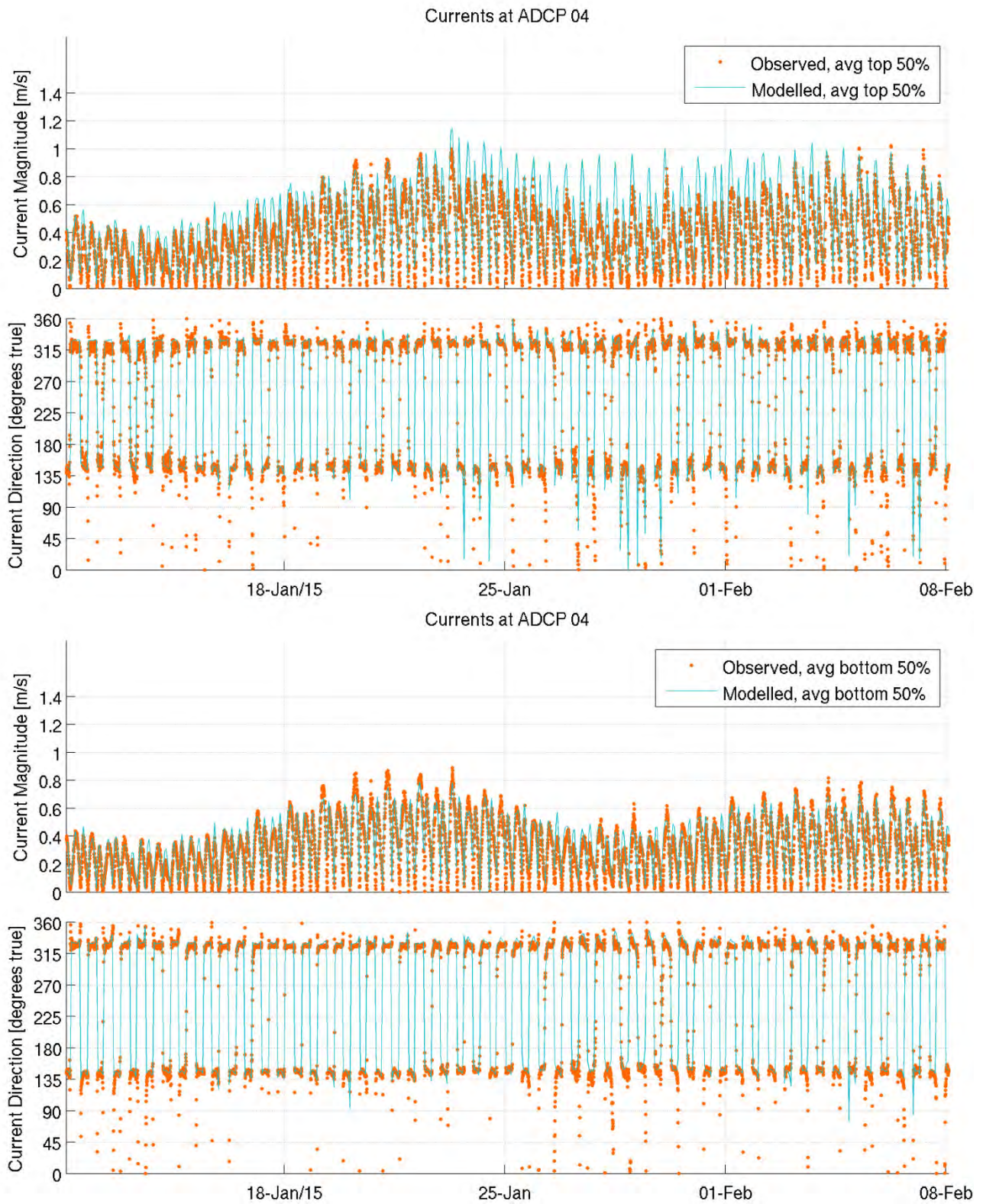


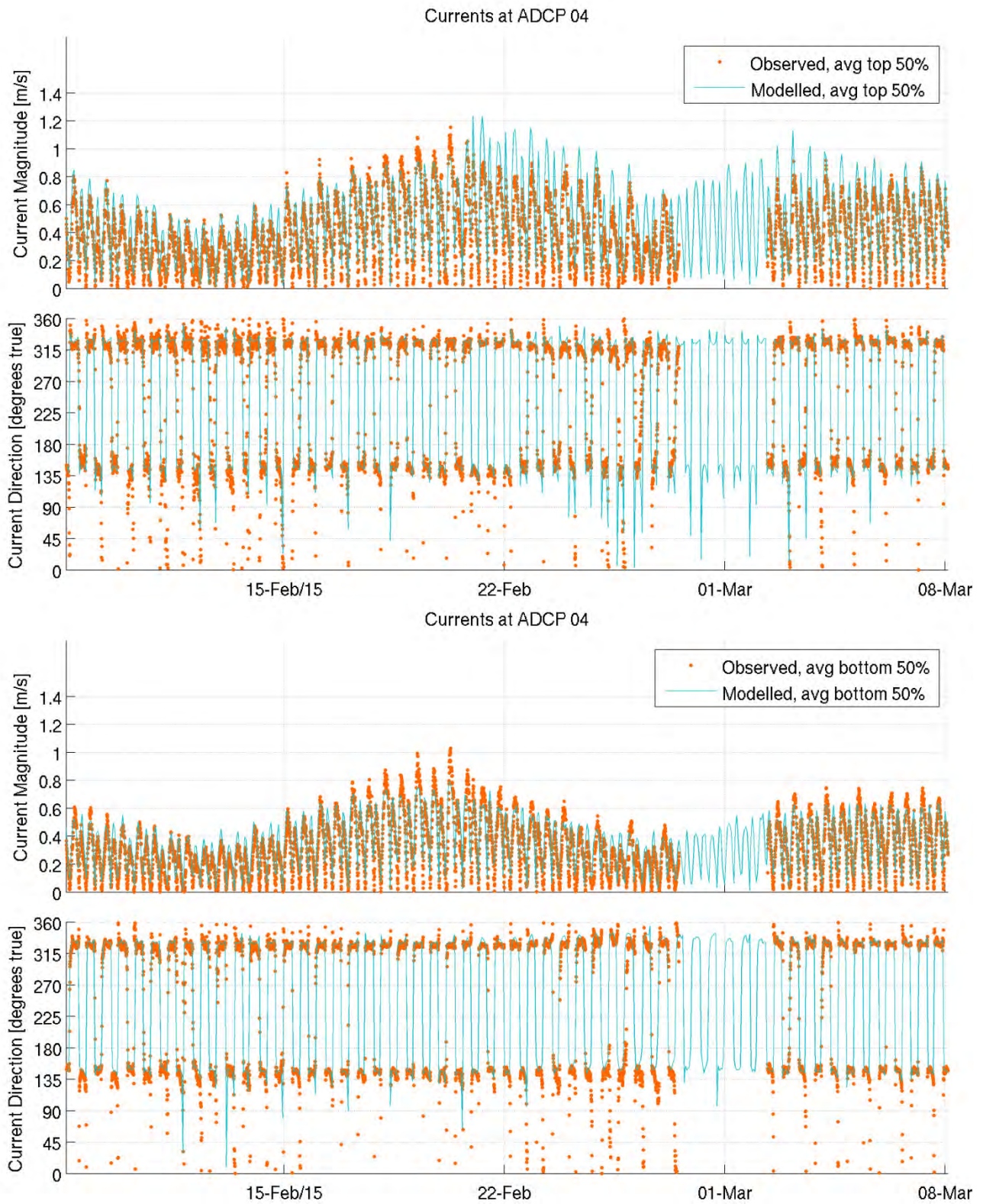


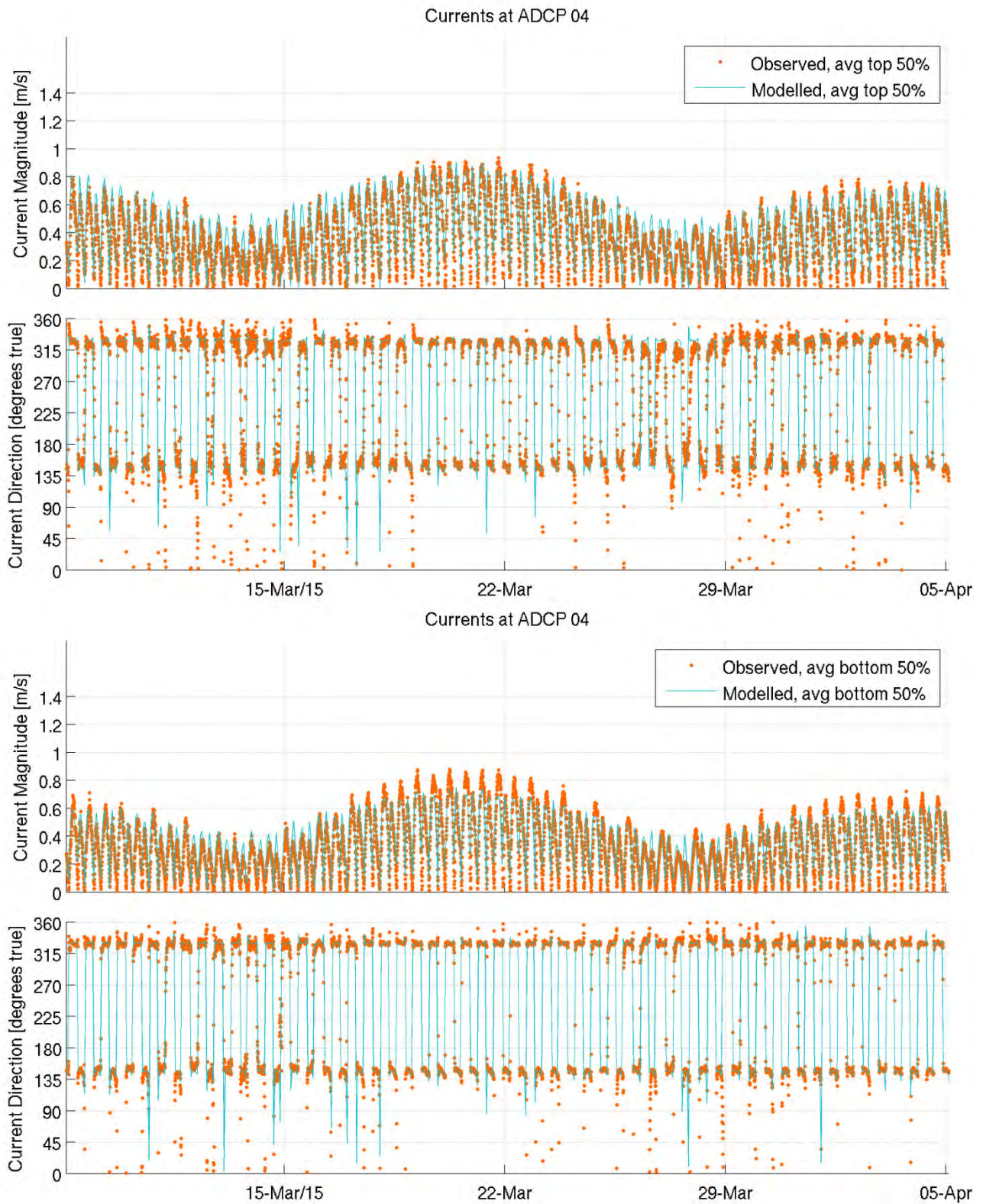


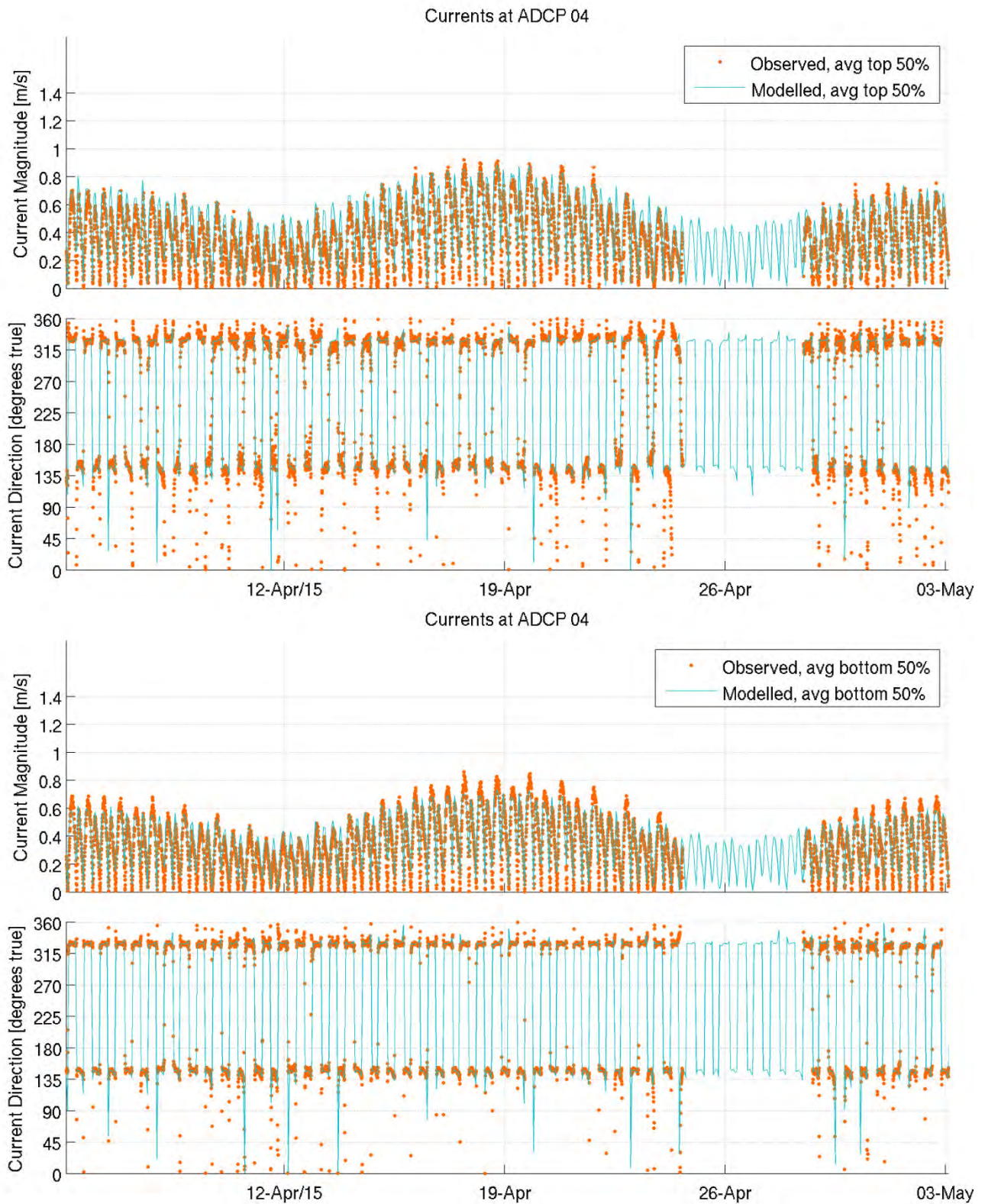


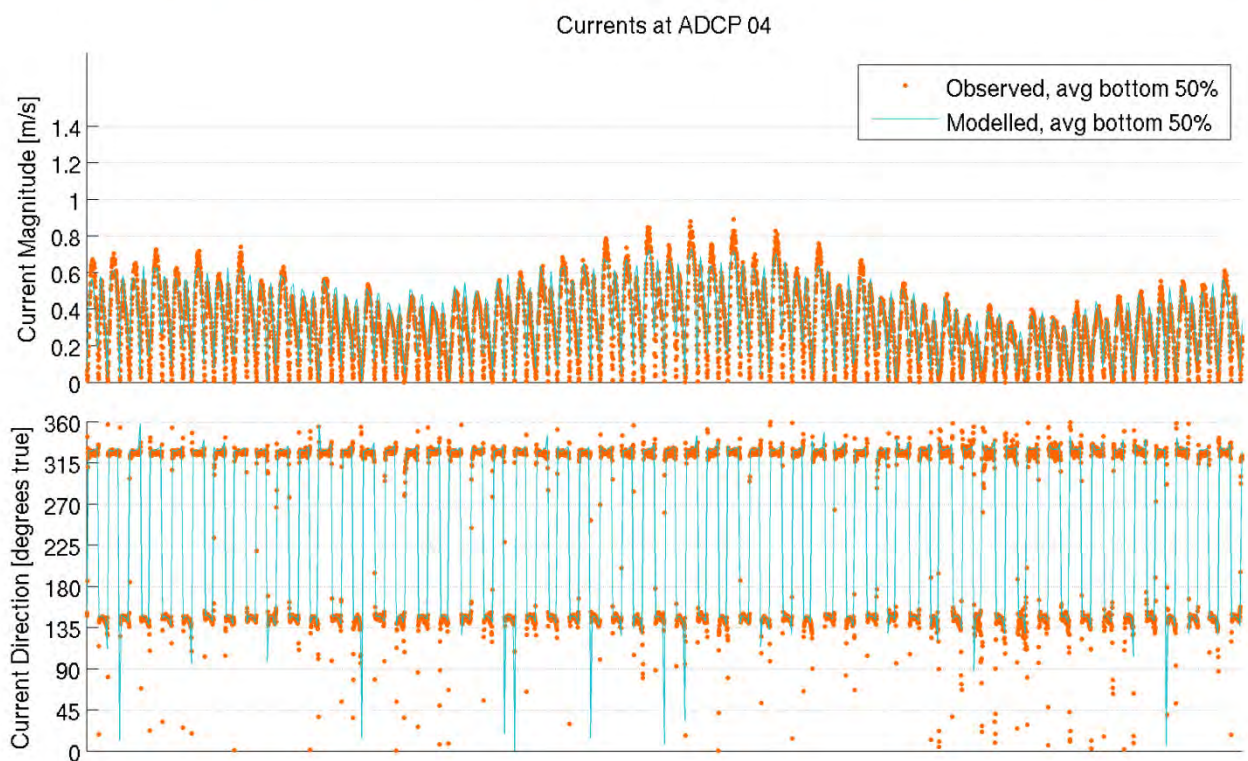
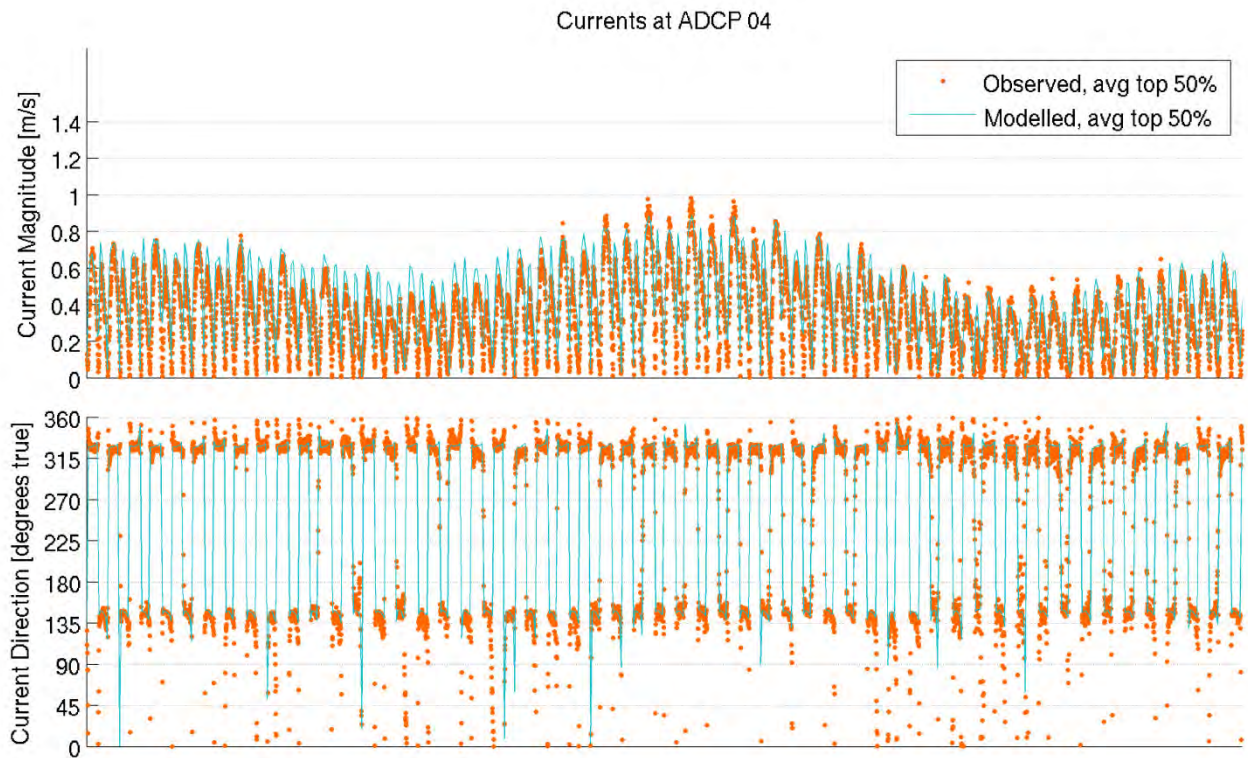


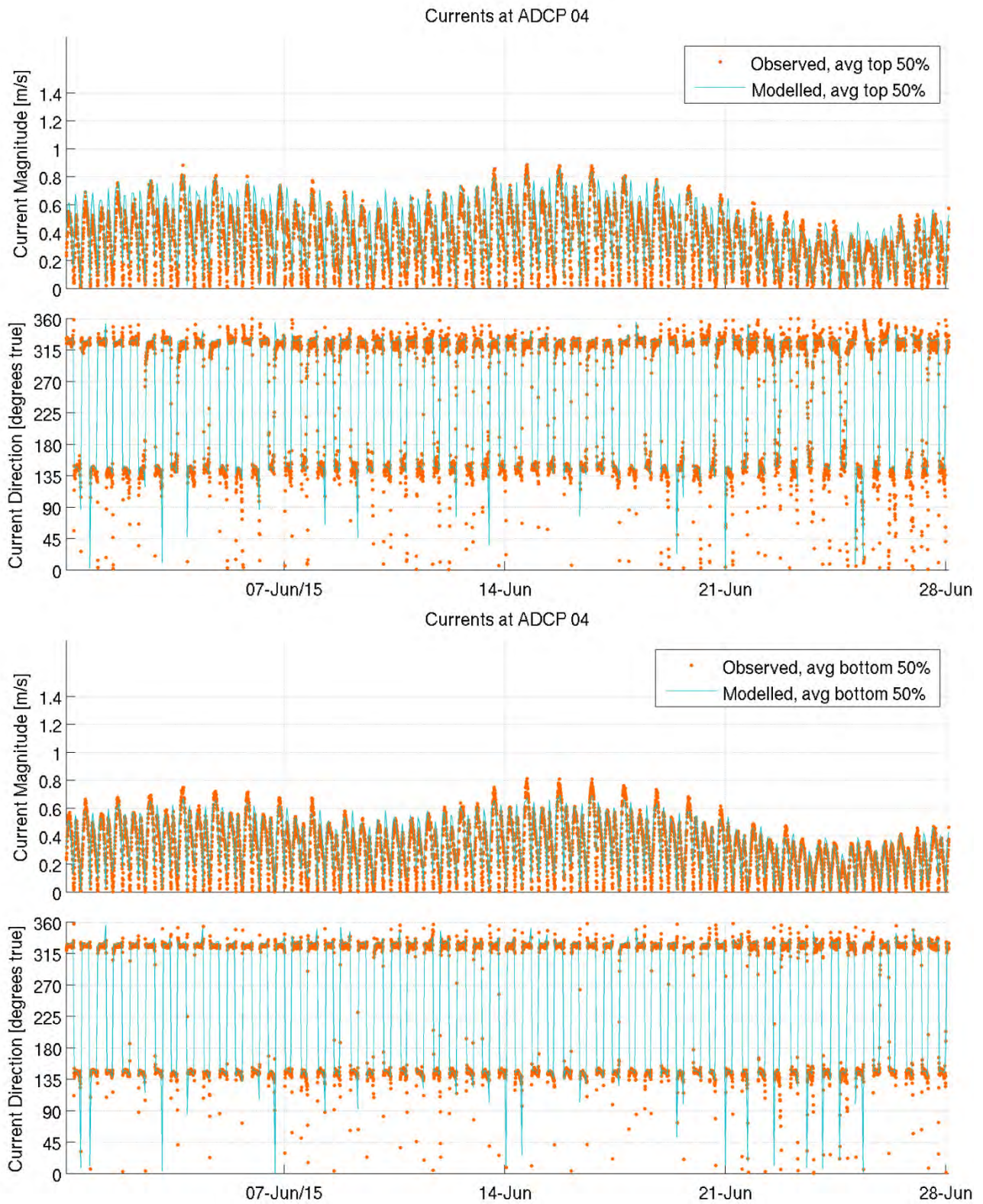


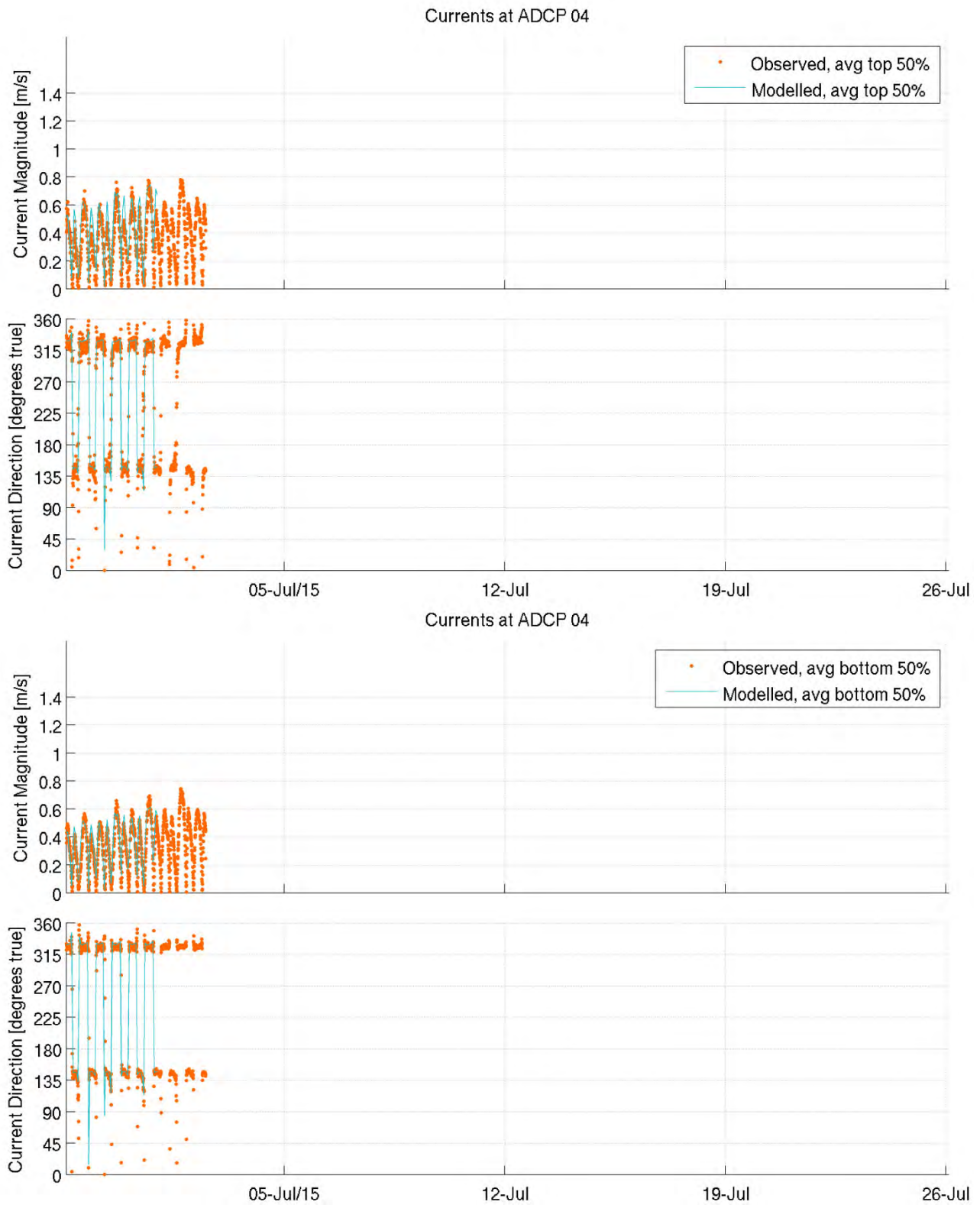


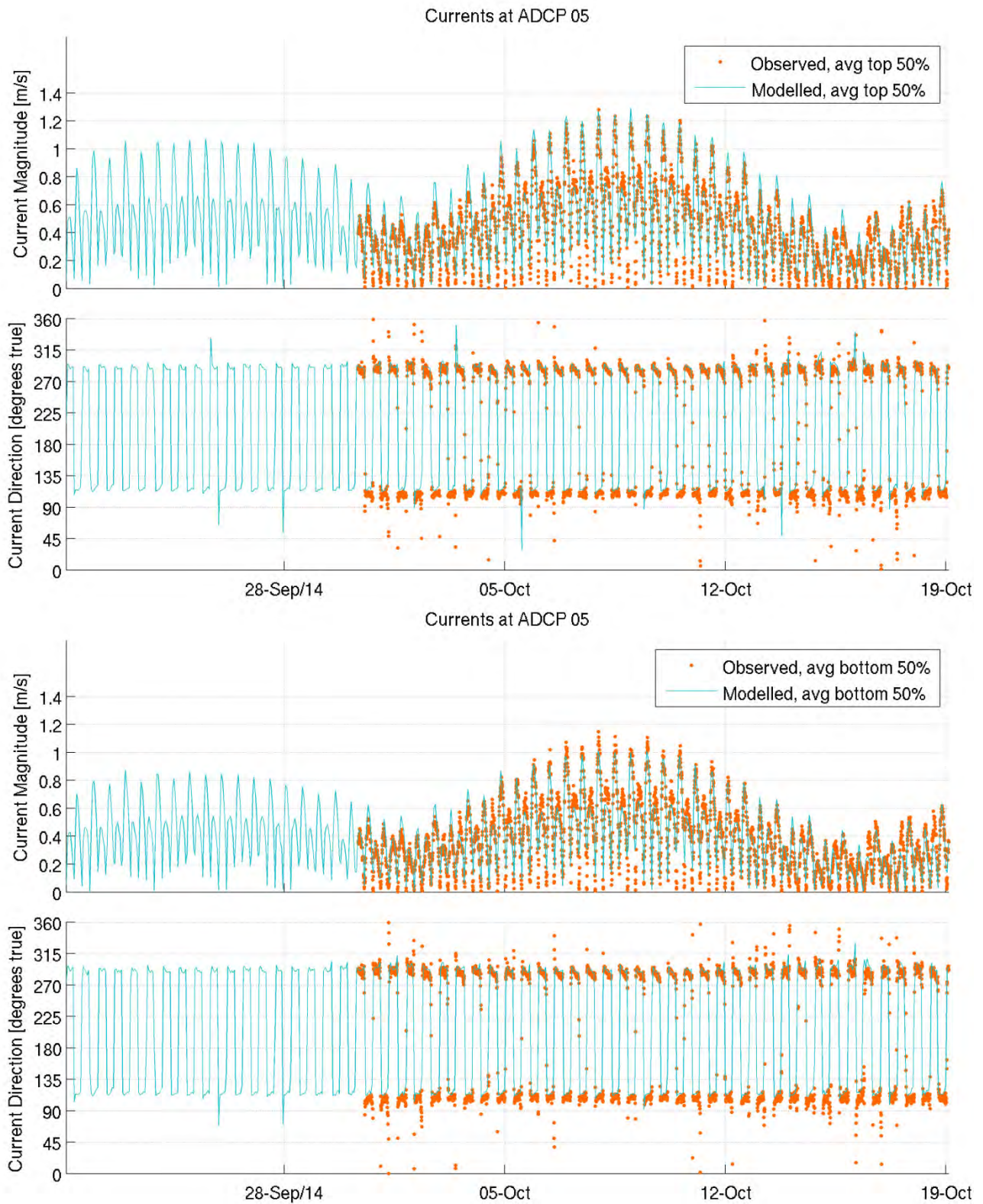


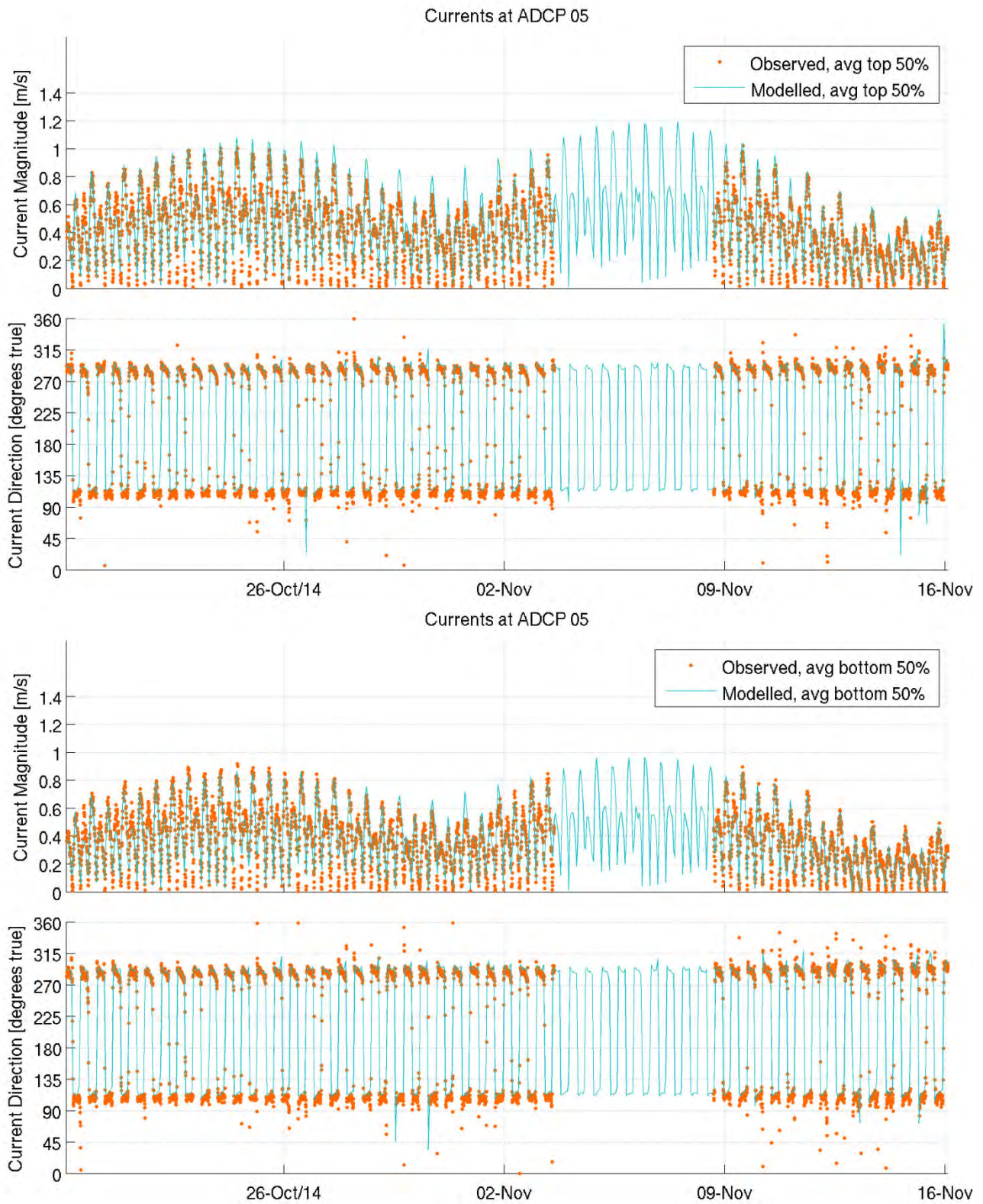


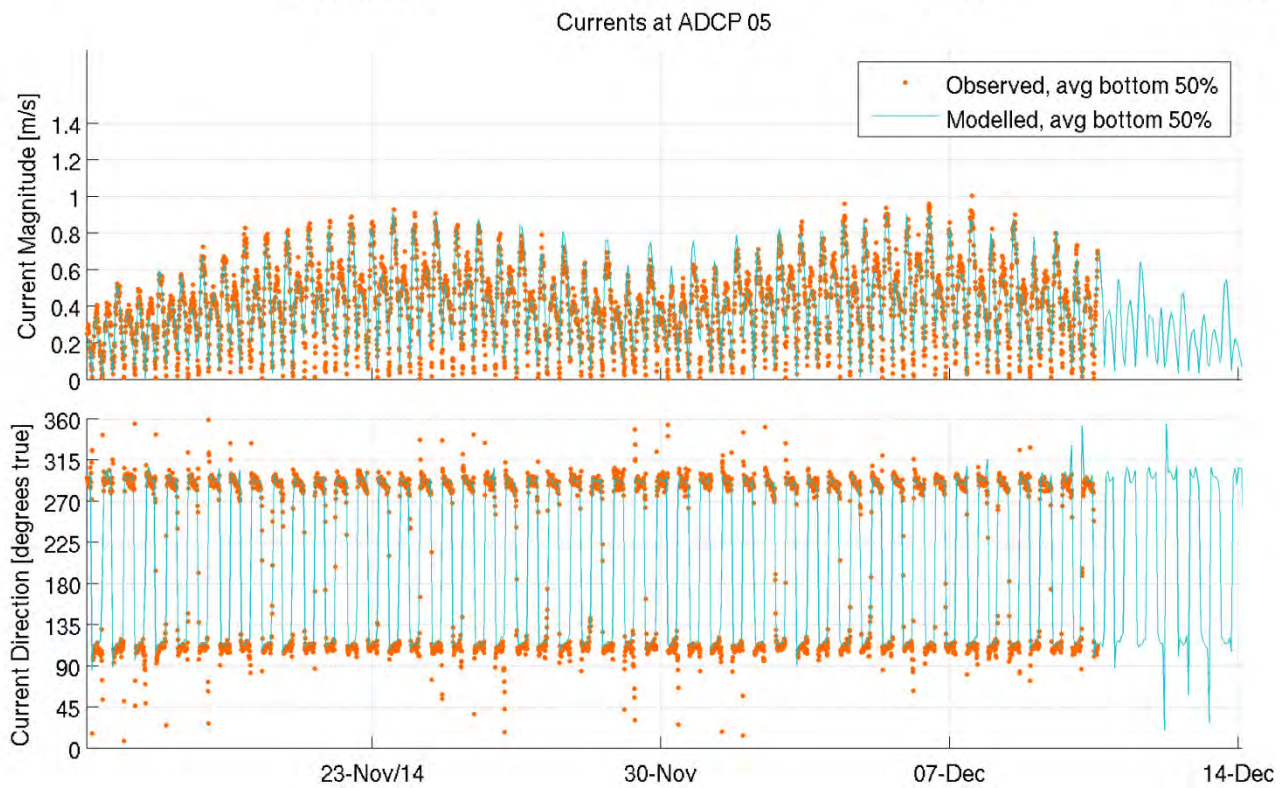
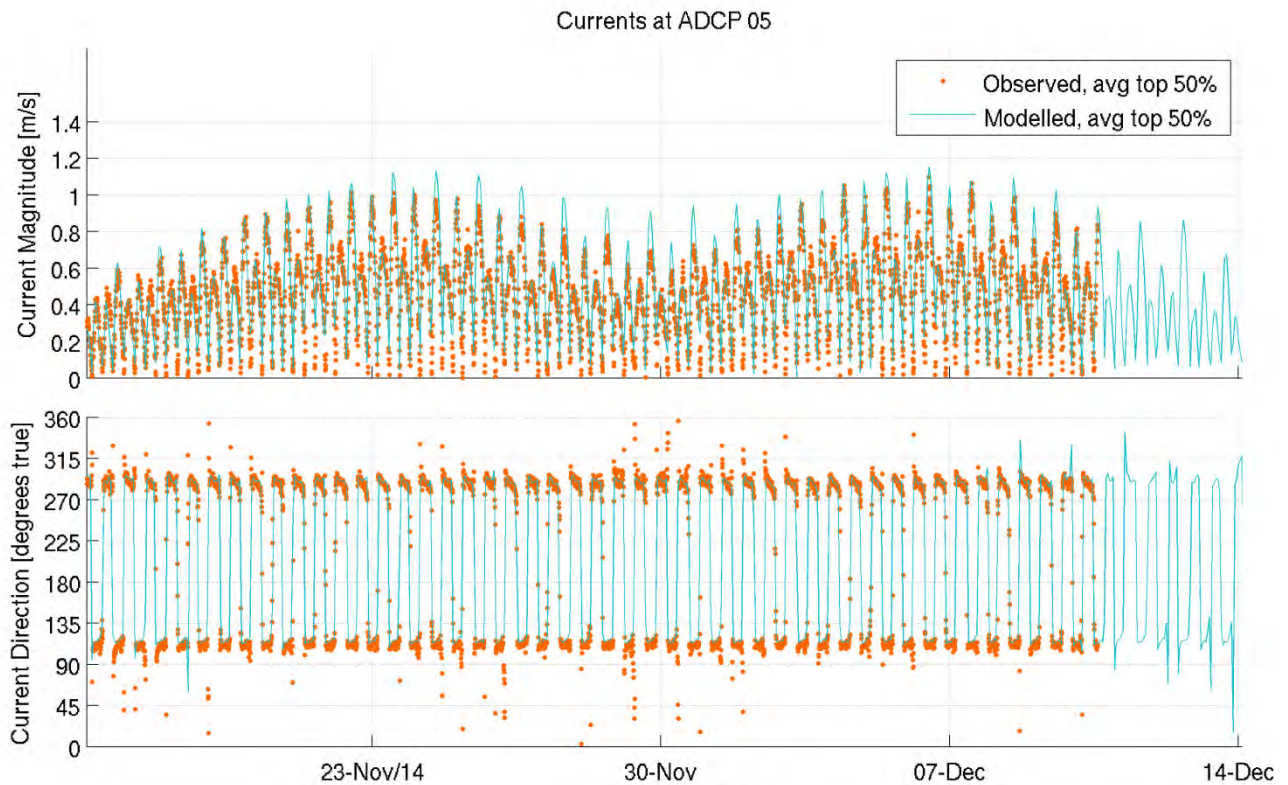


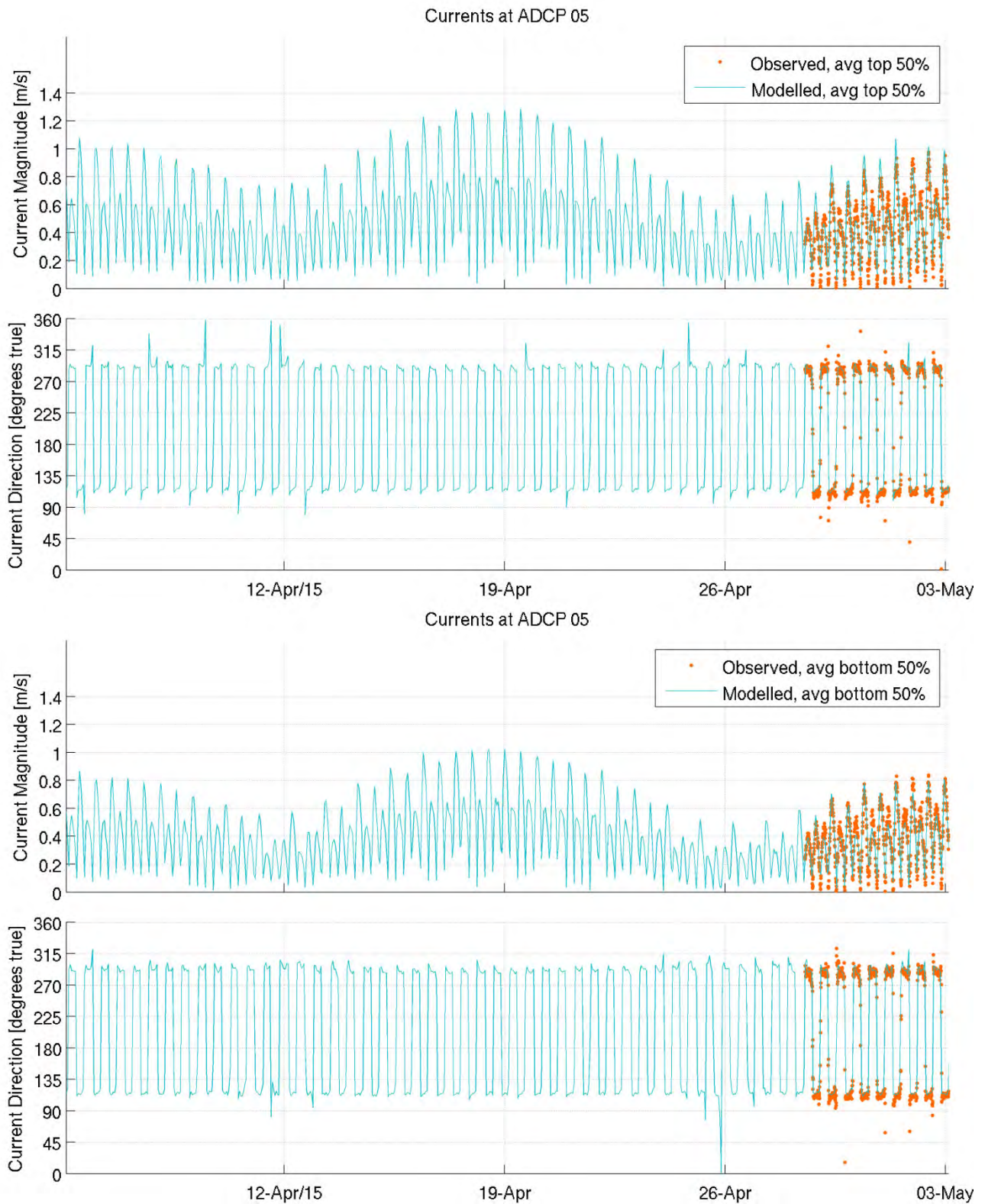


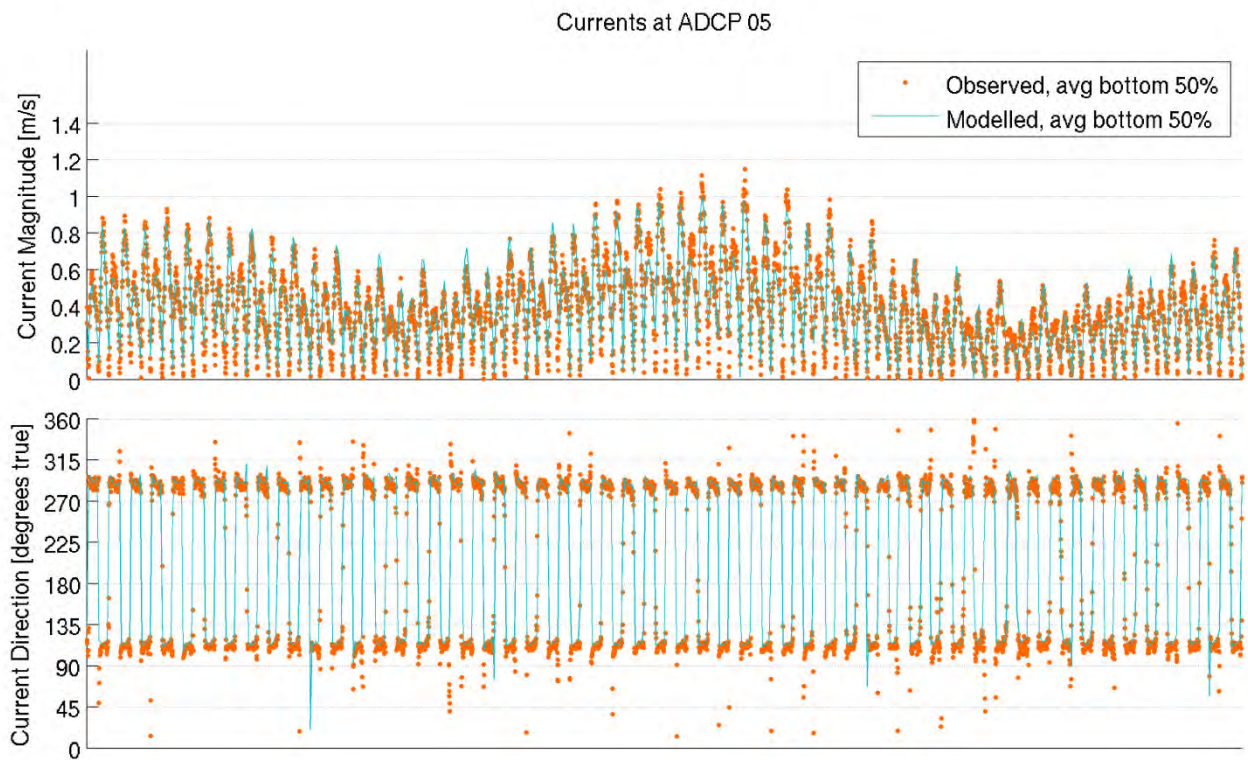
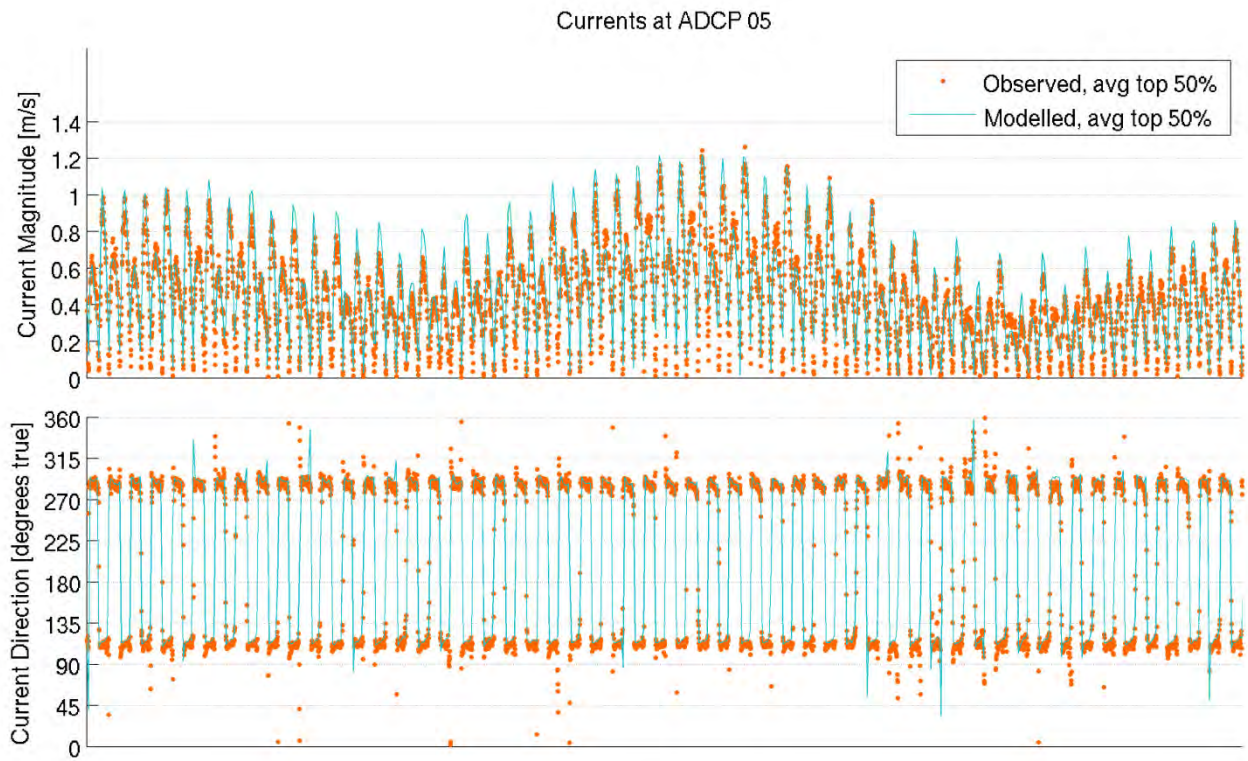


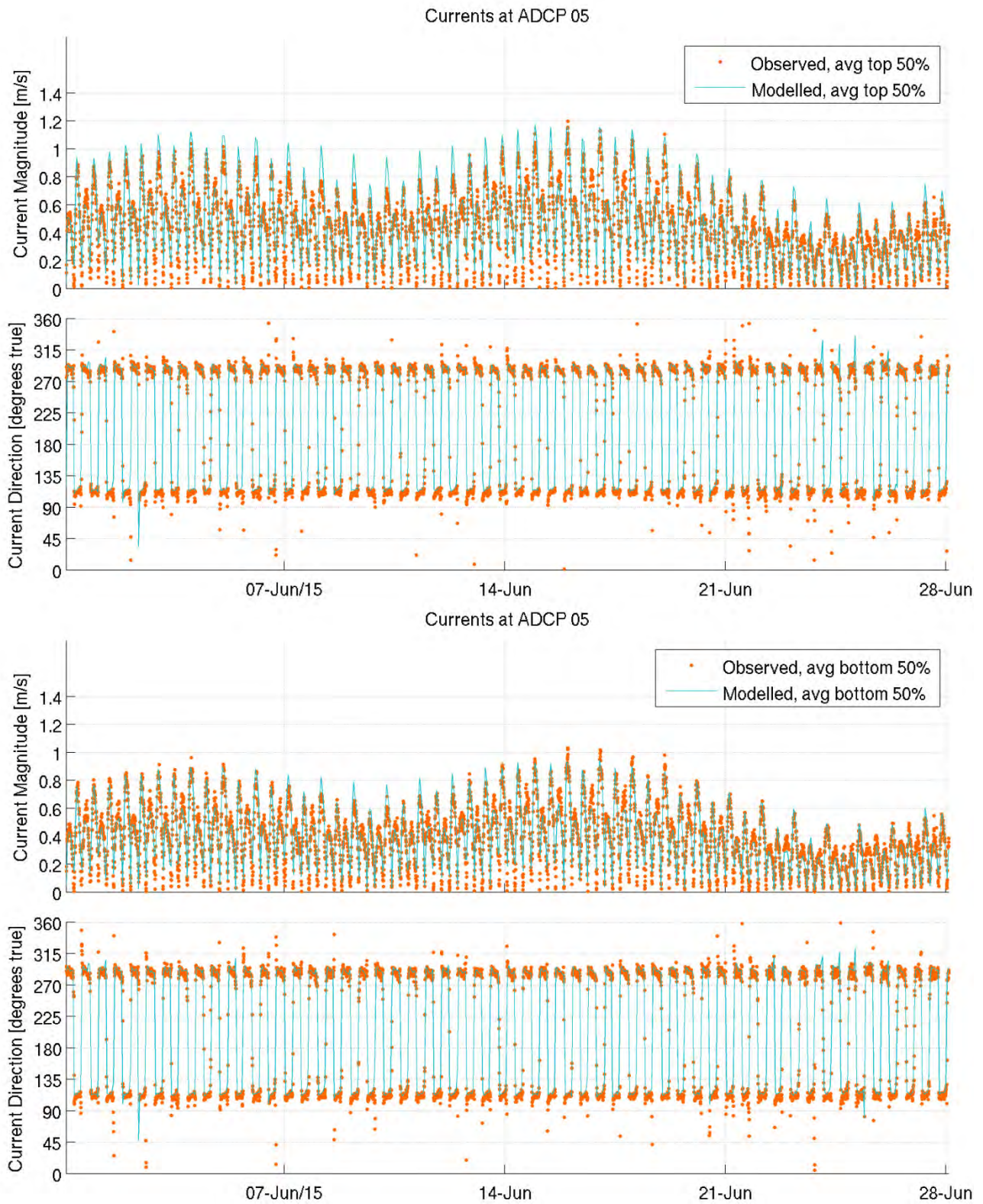


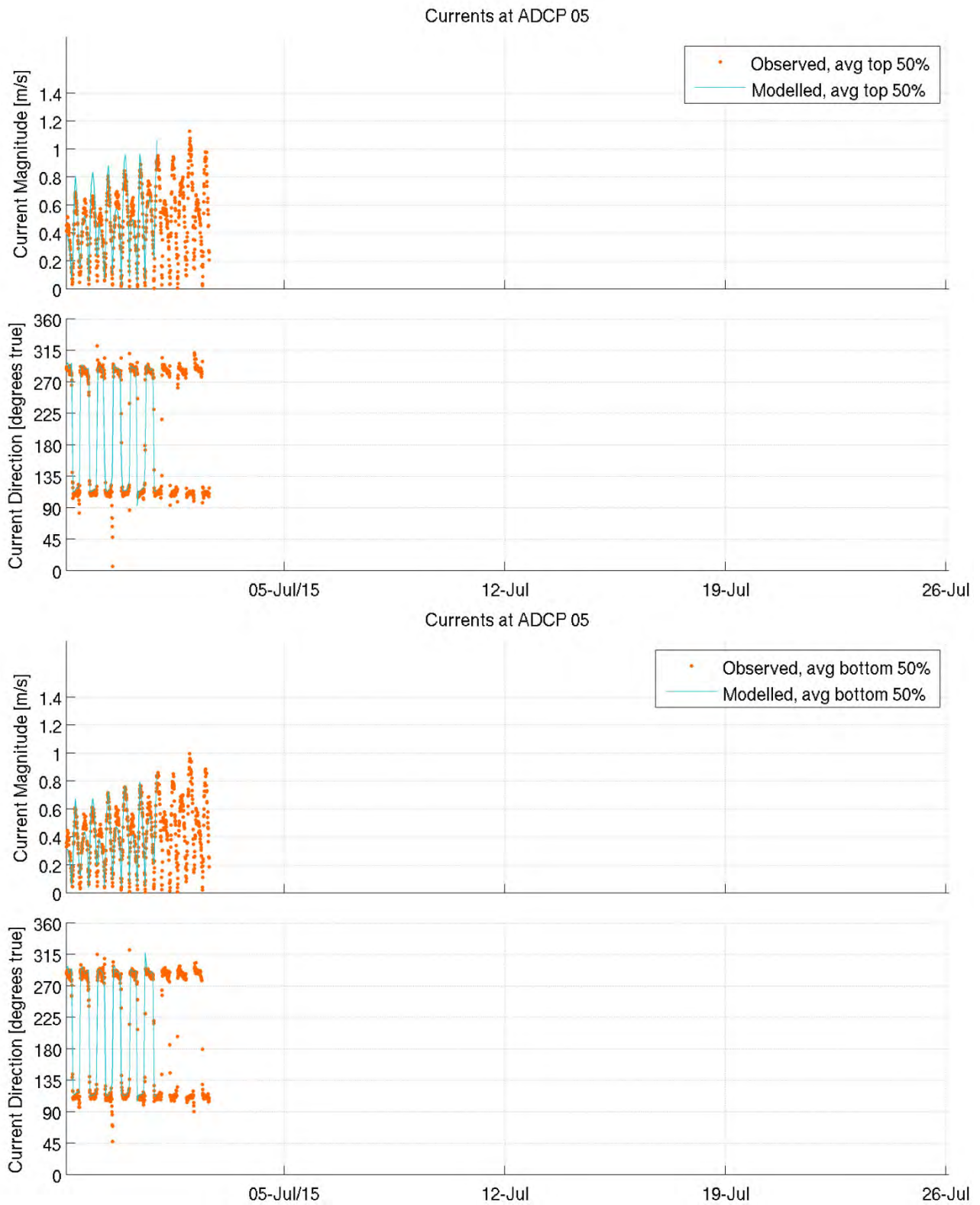


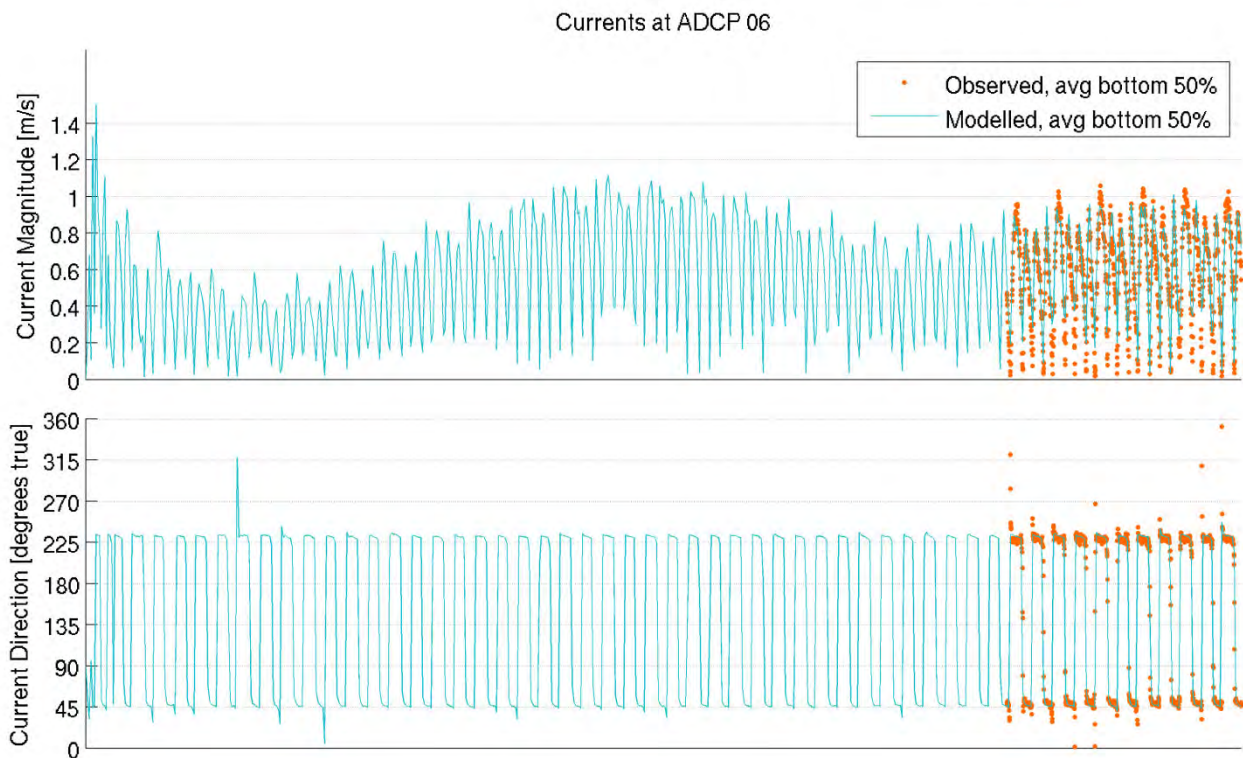
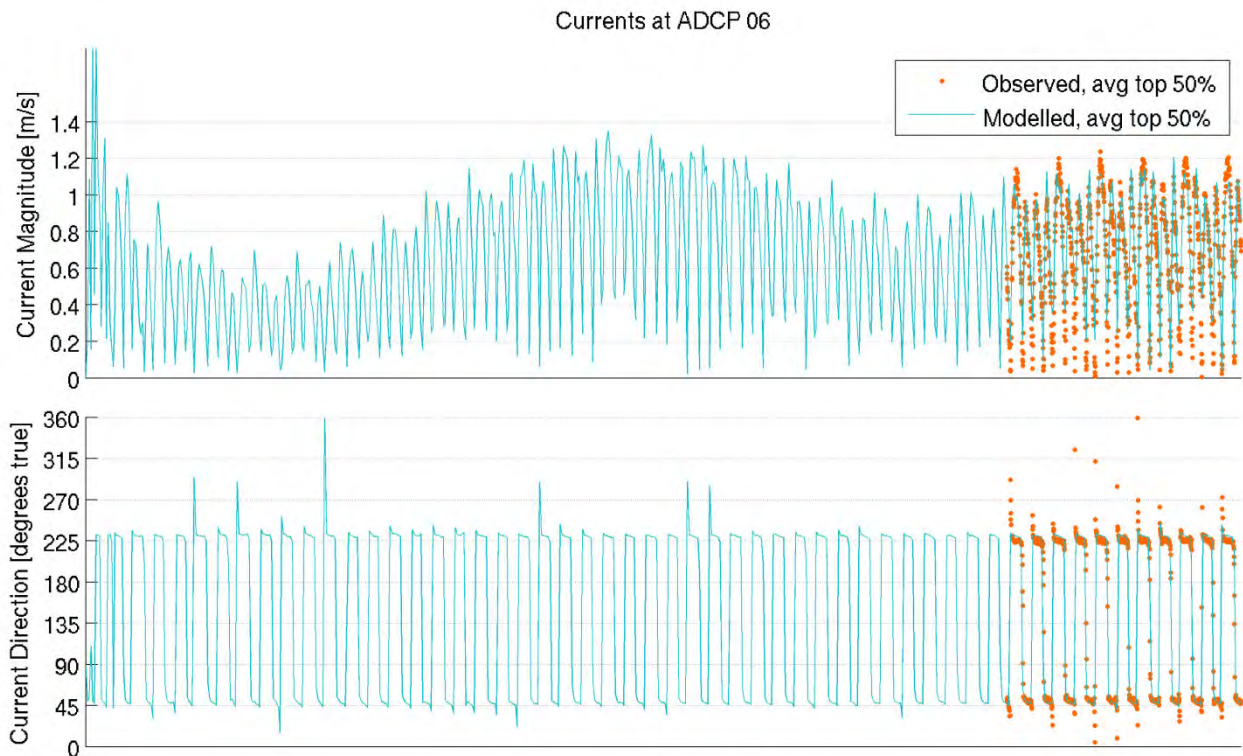


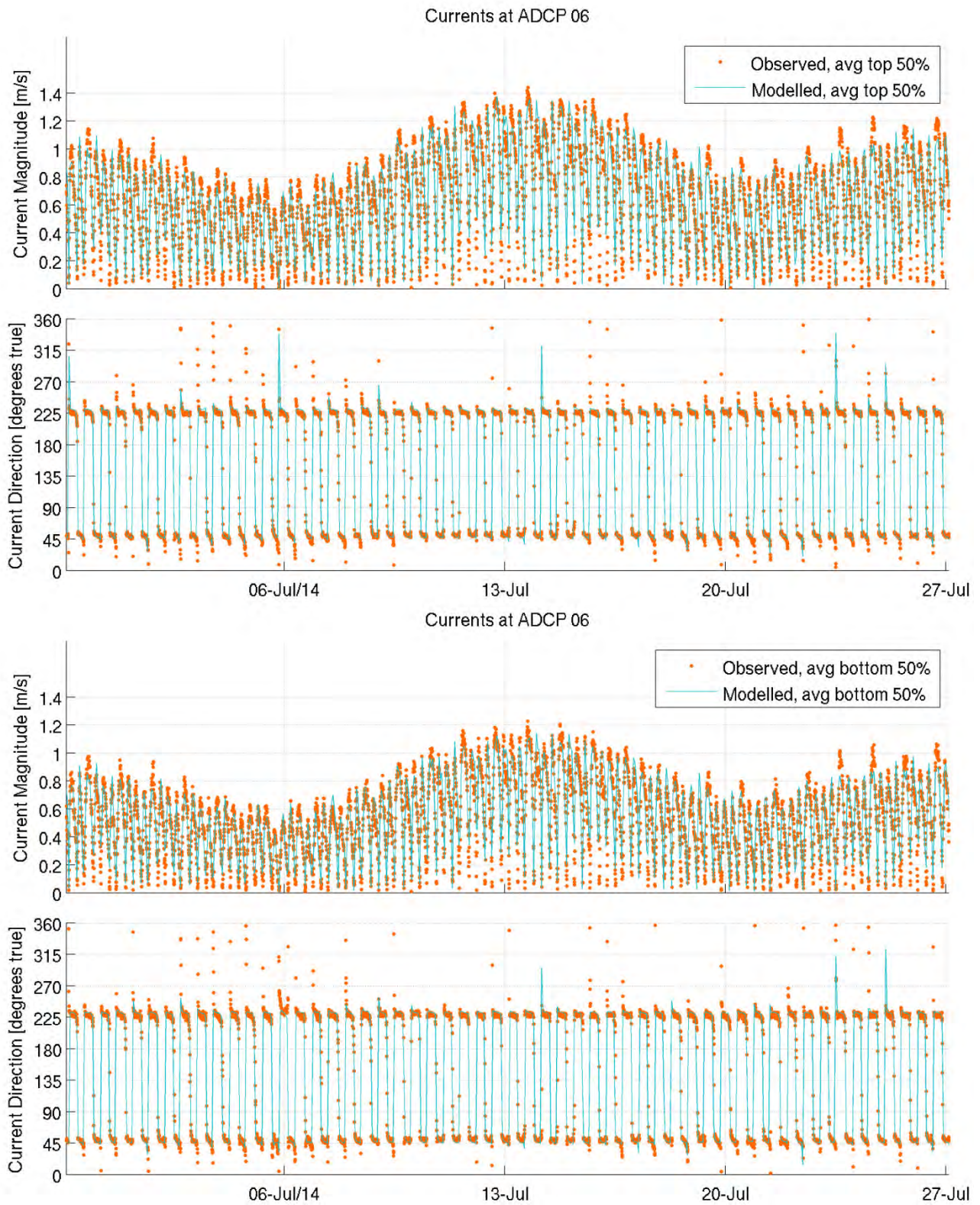


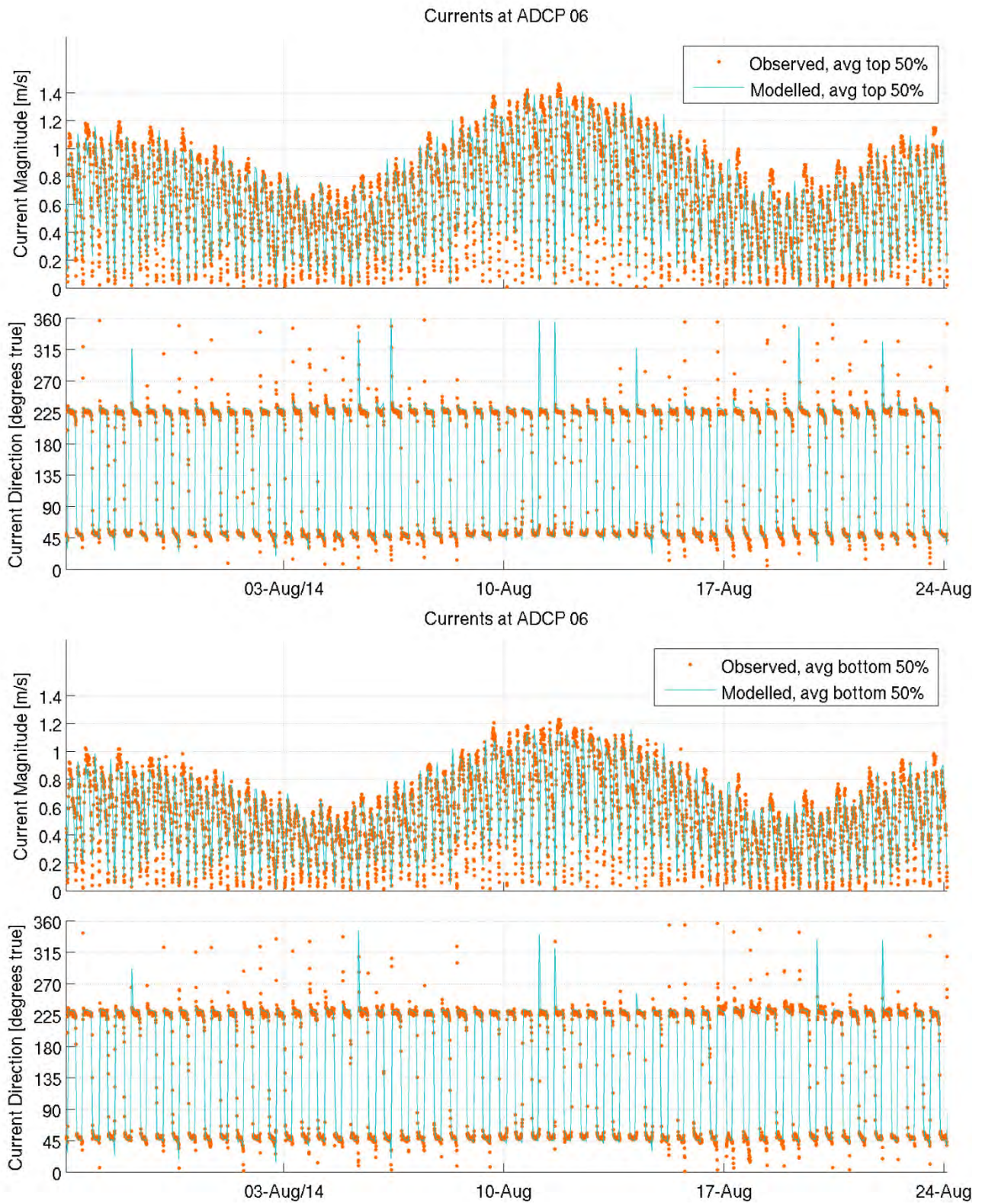


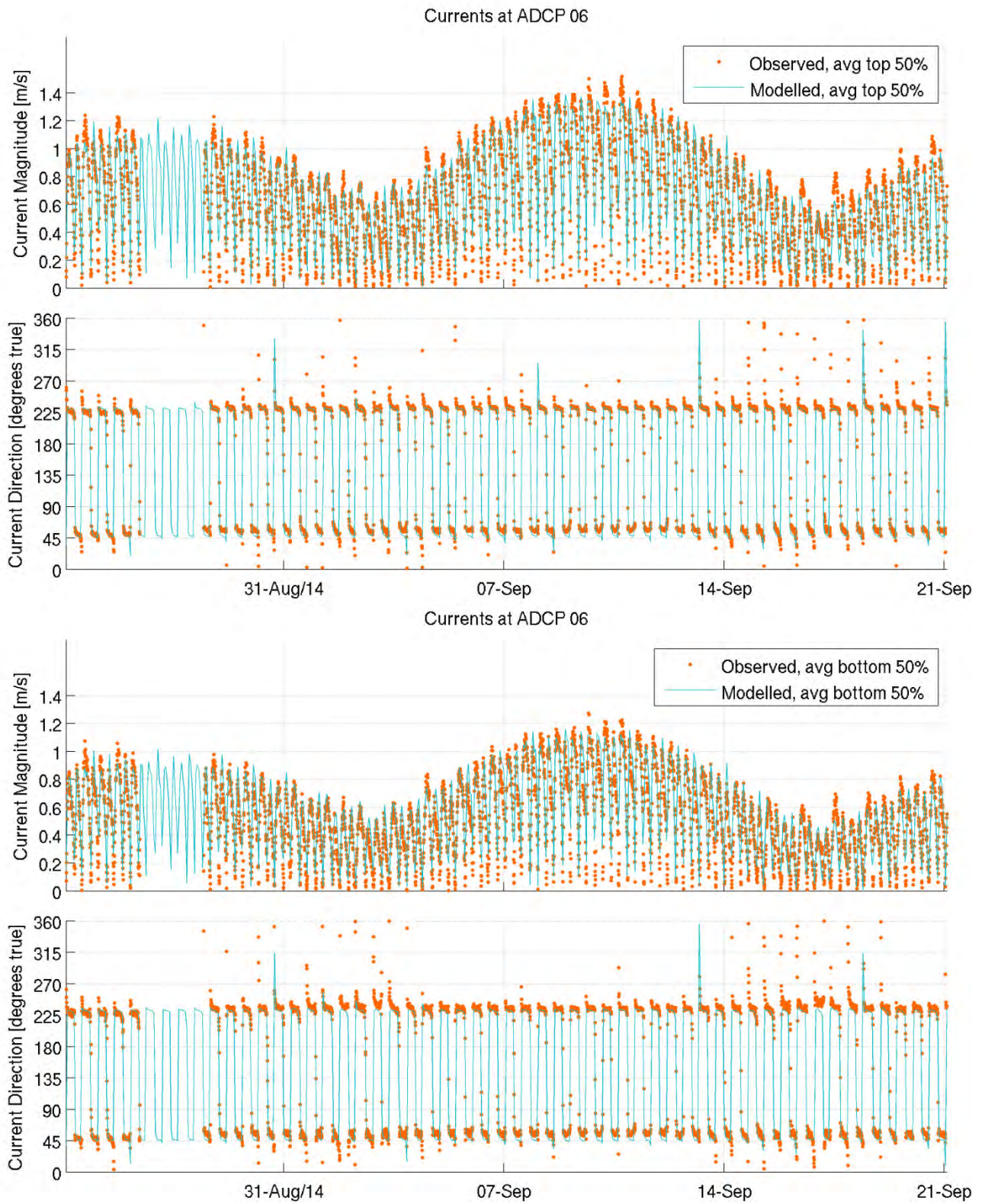


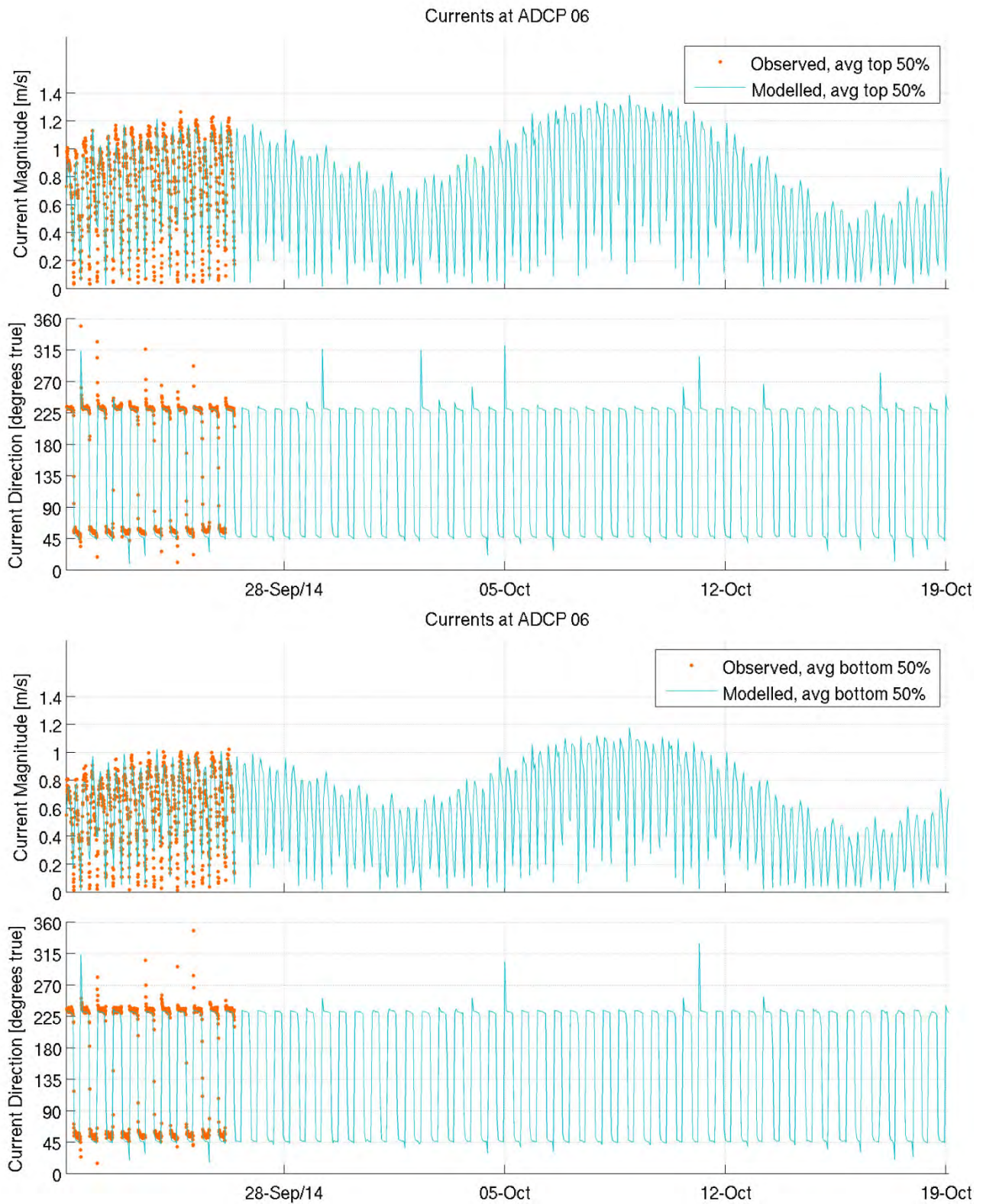


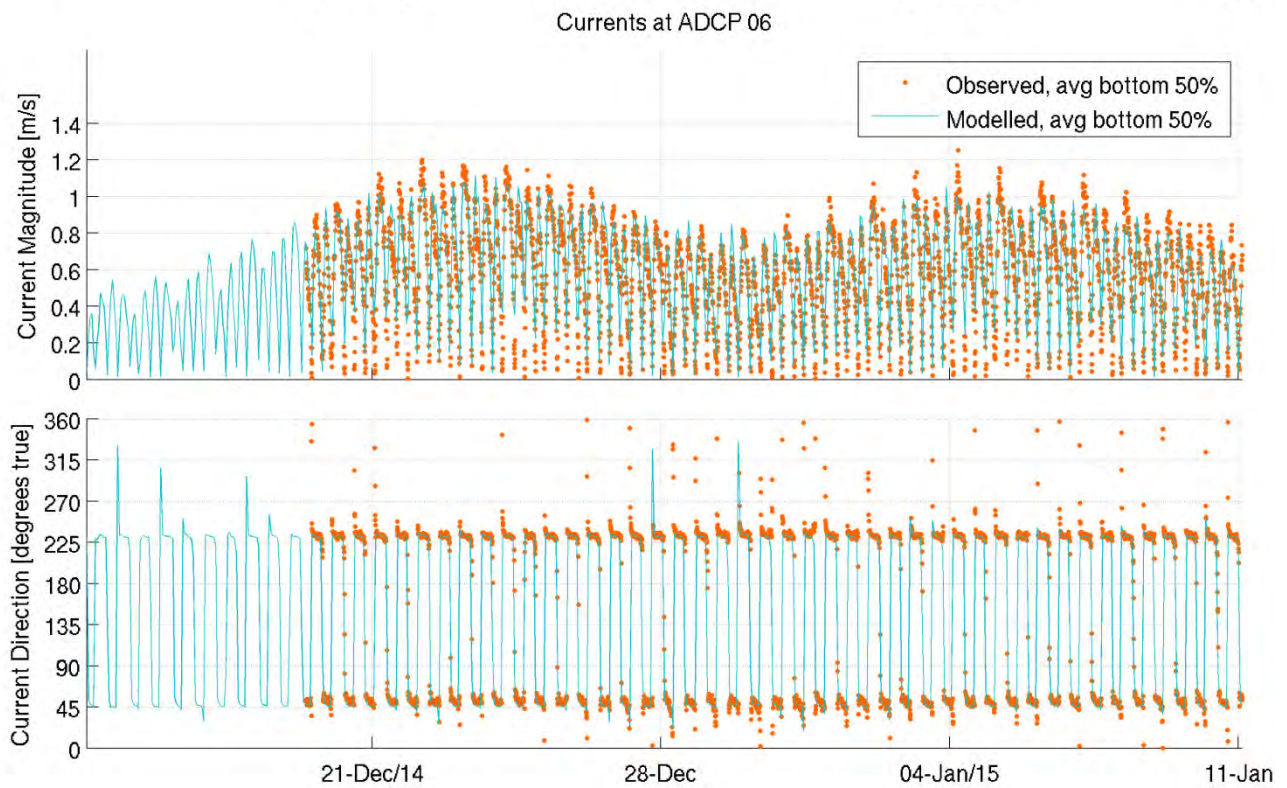
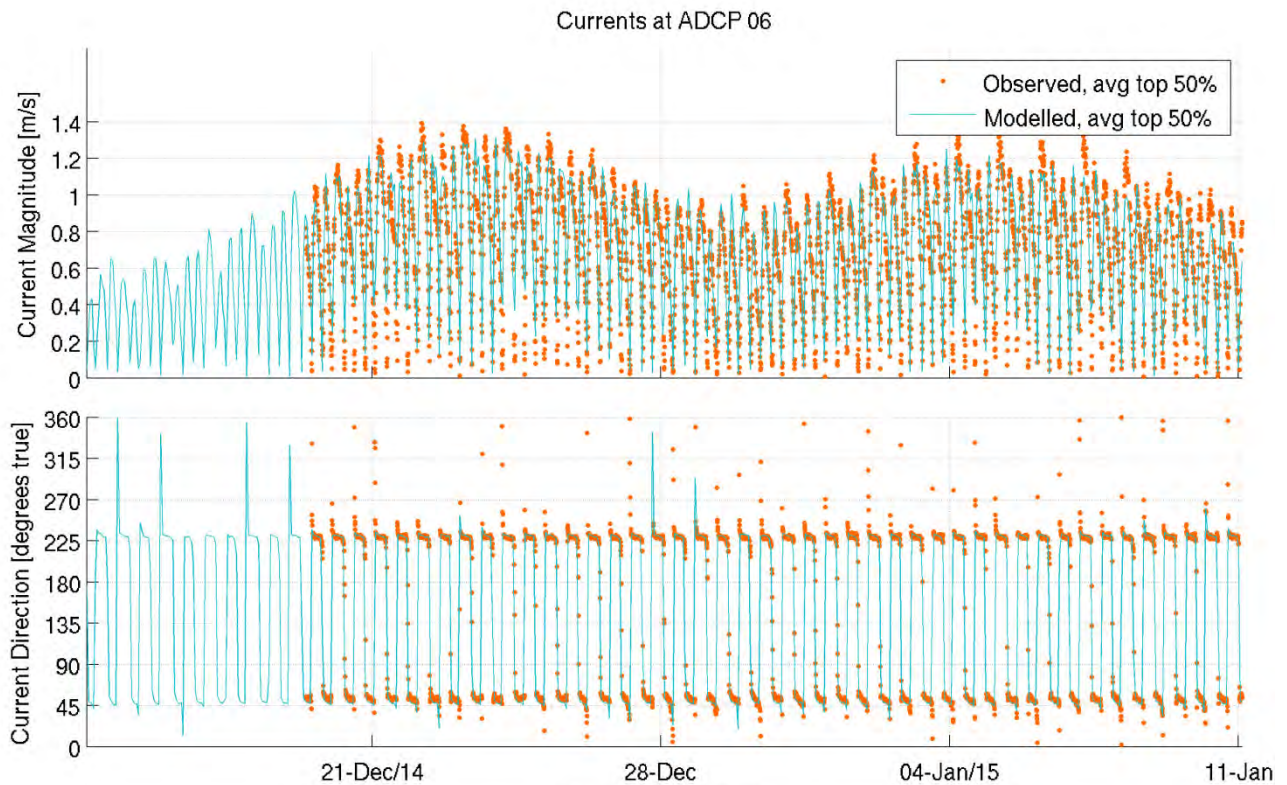


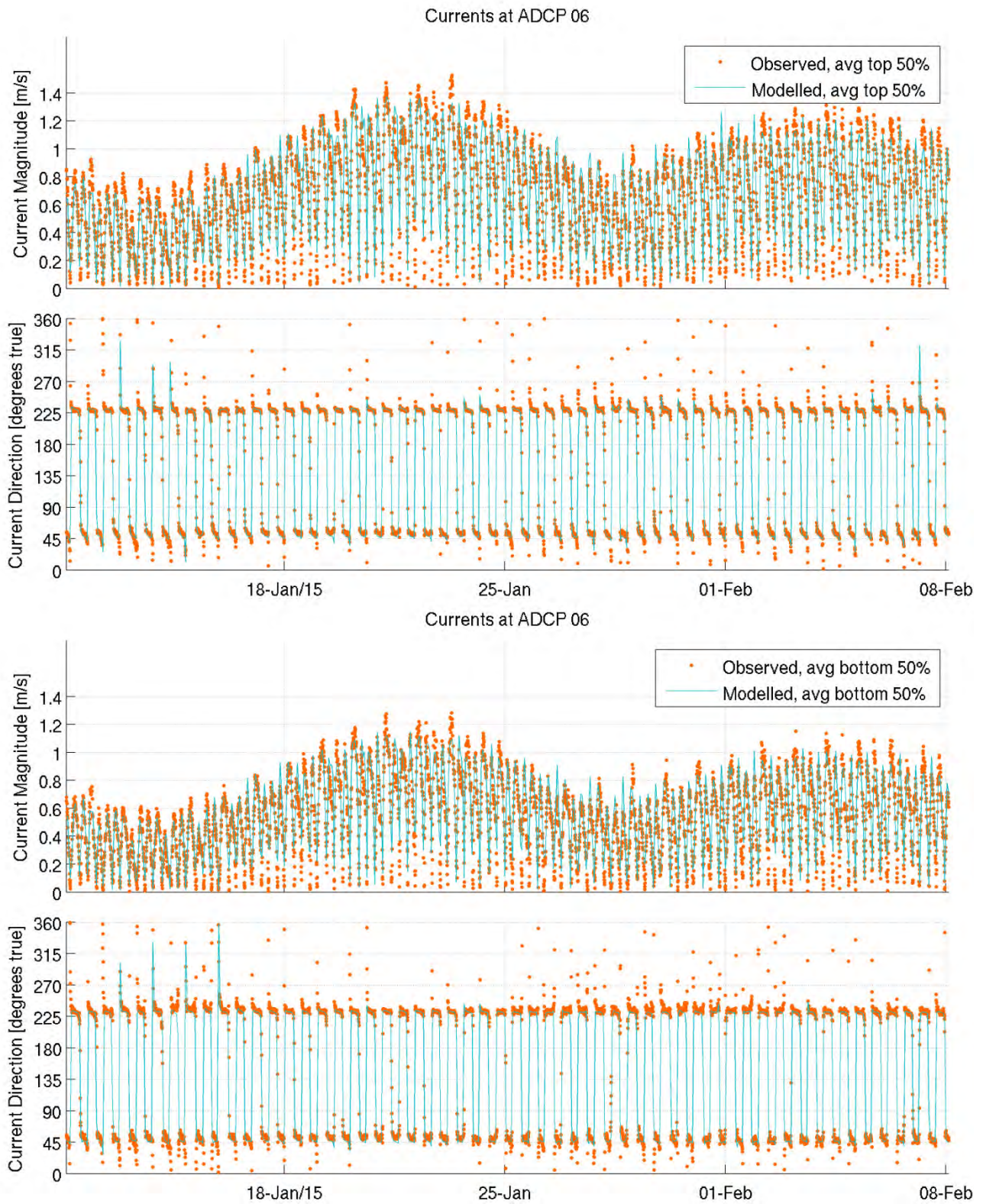


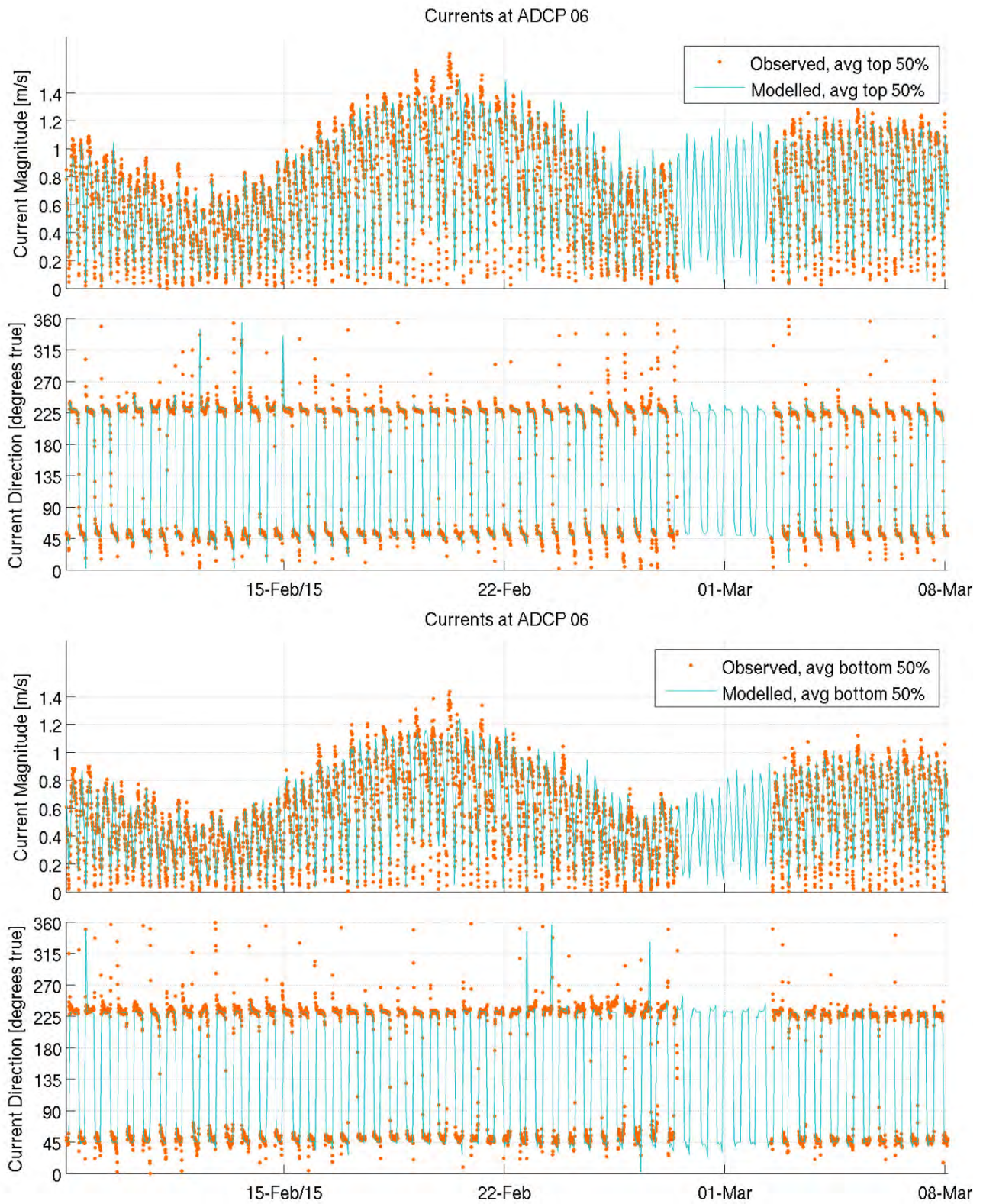


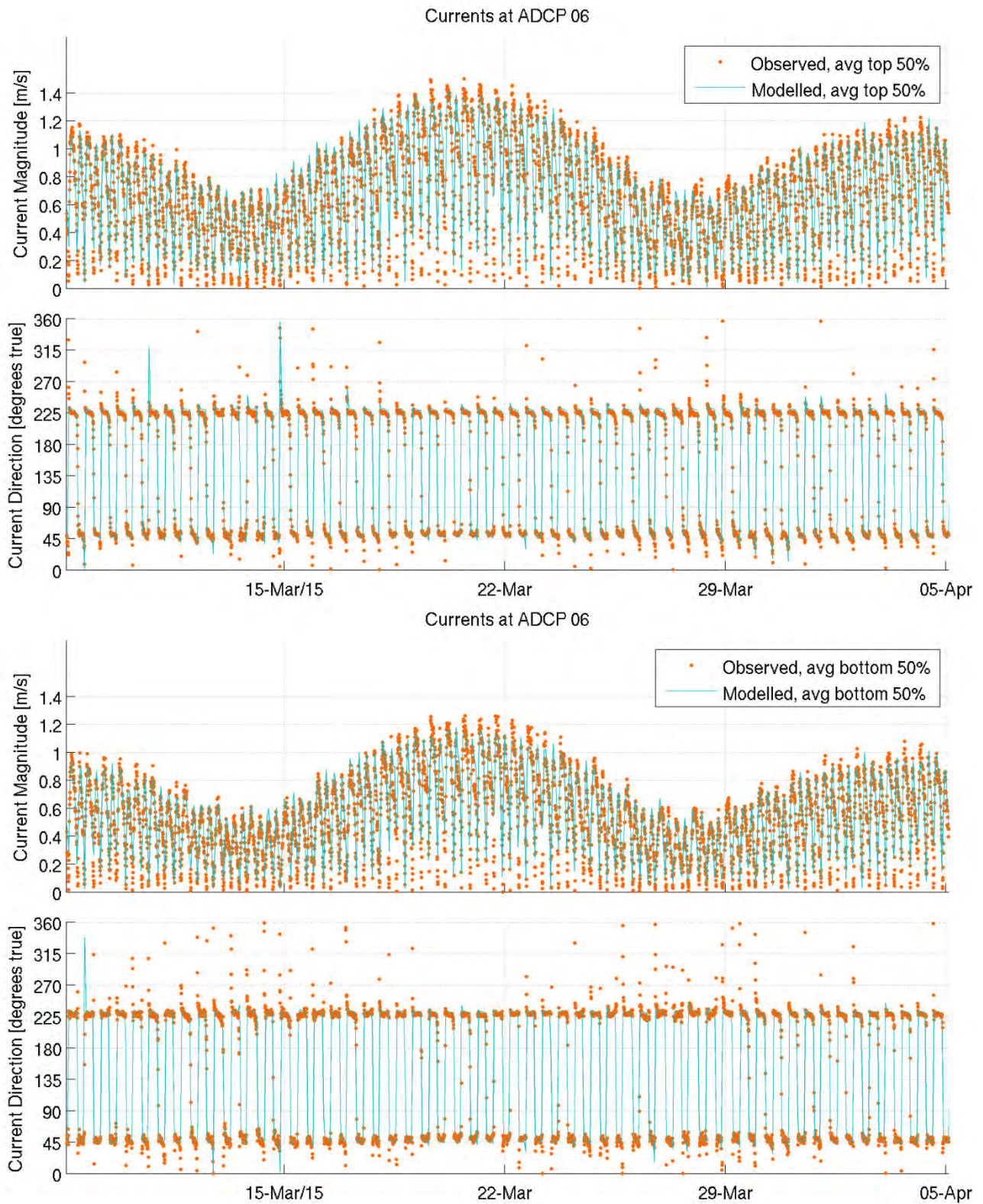


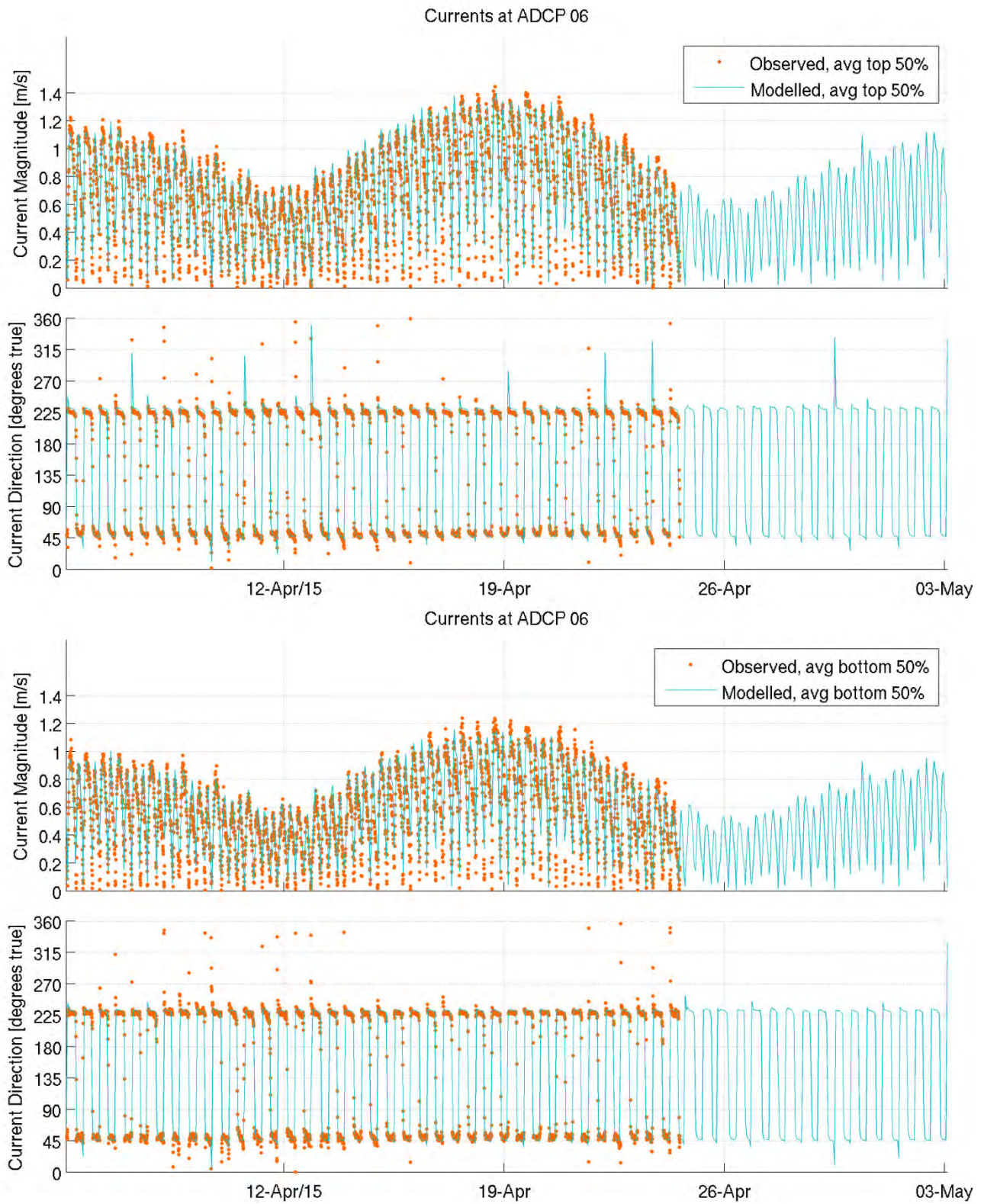




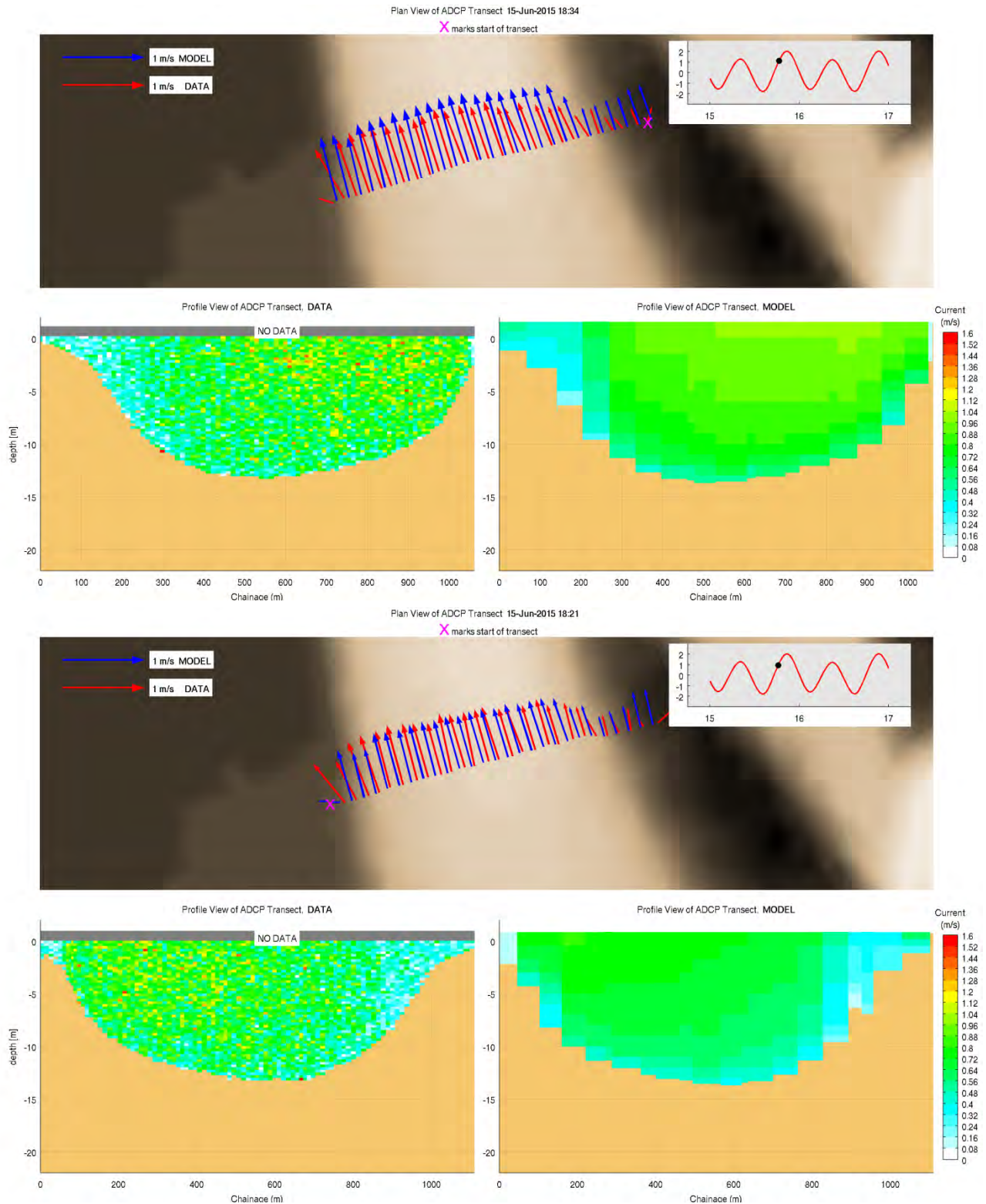


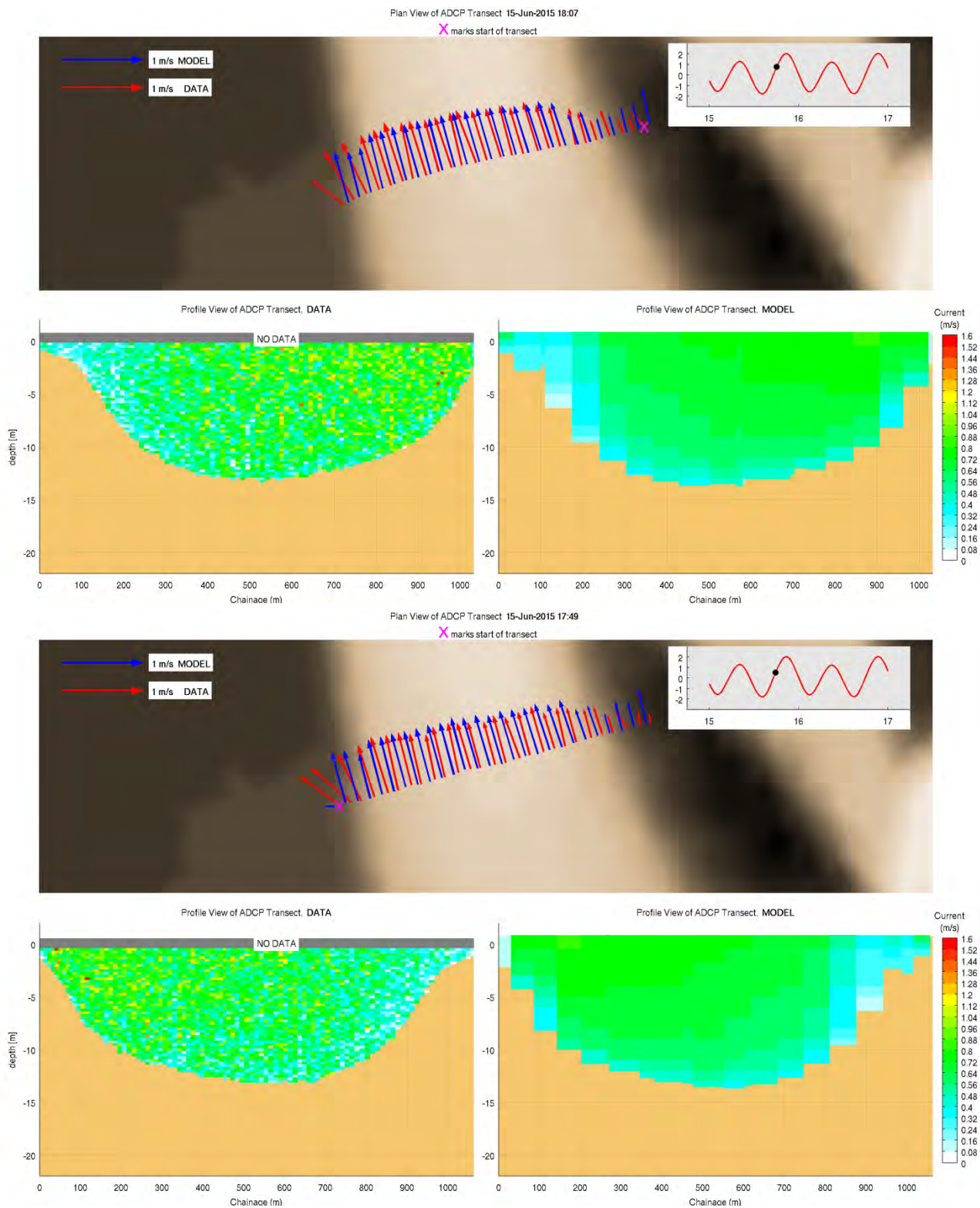


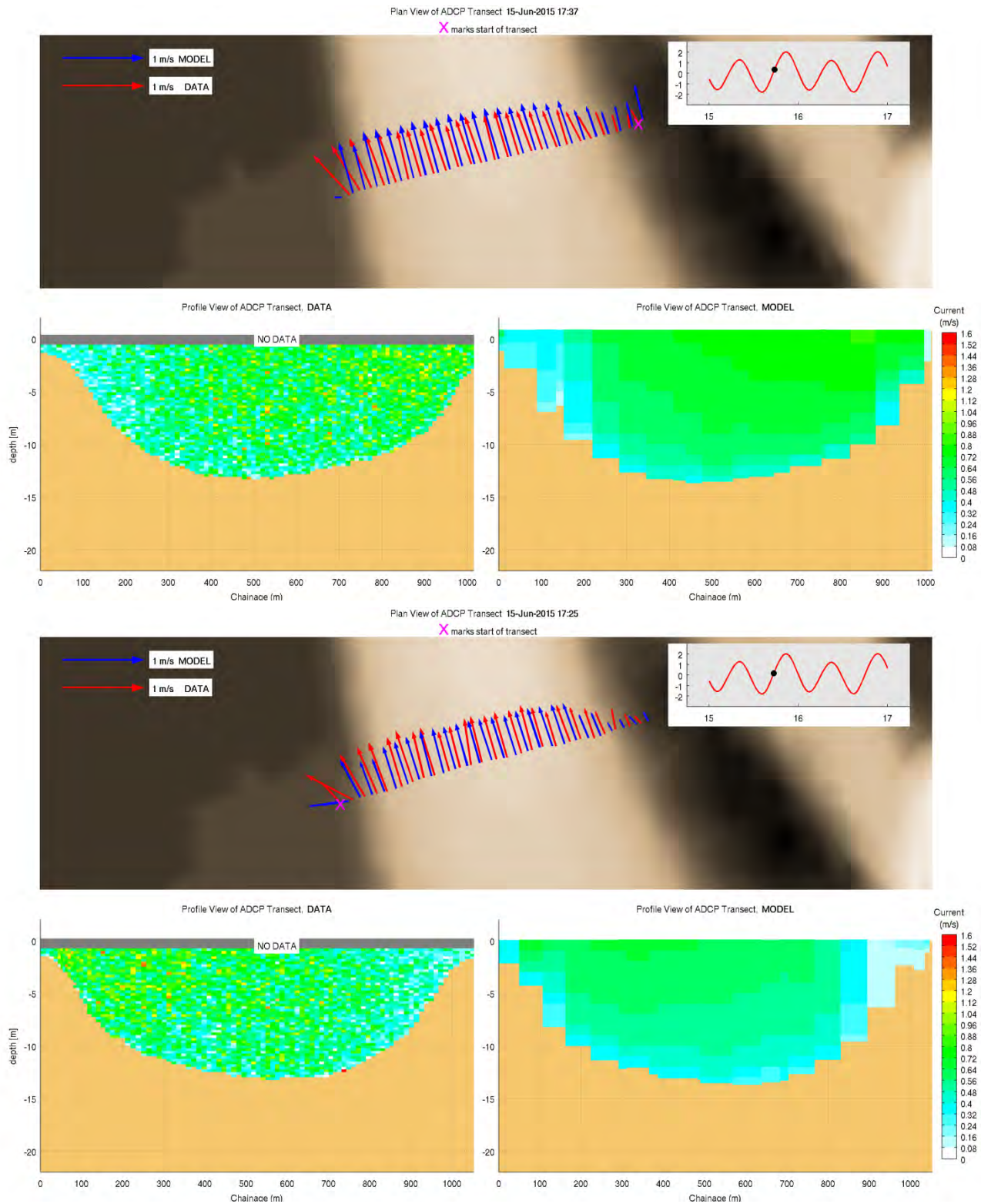


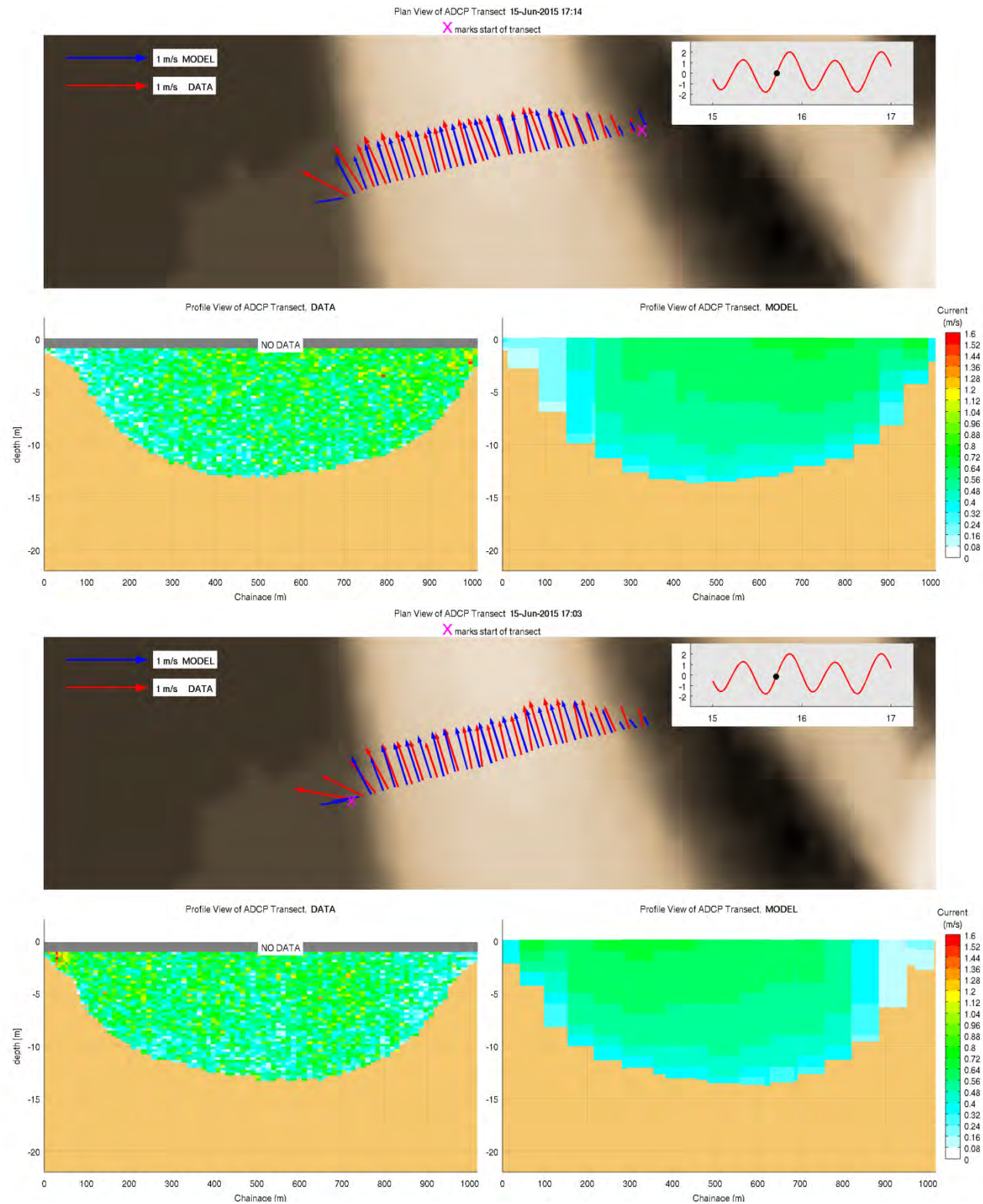


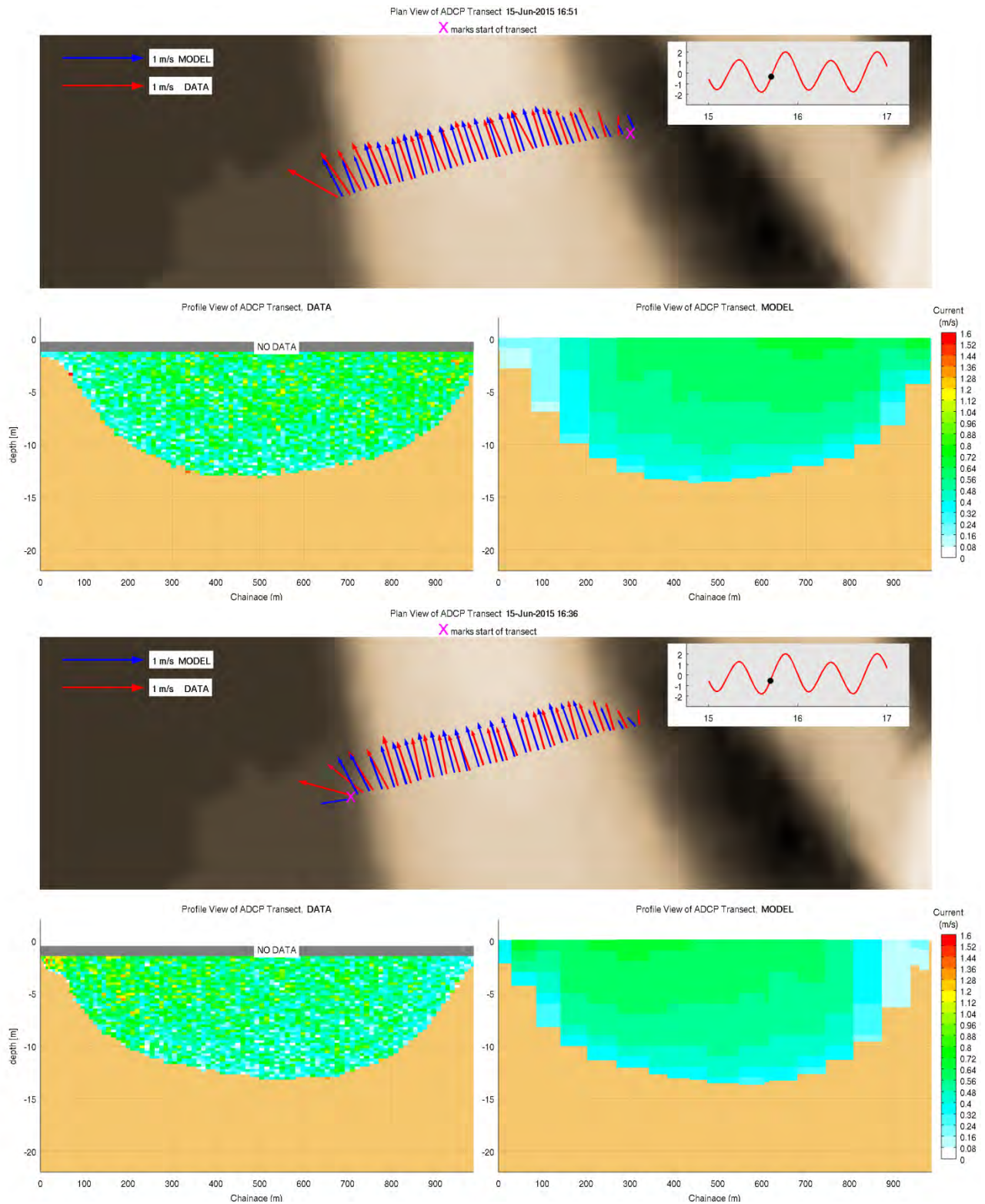
Appendix E ADCP Transect Comparisons

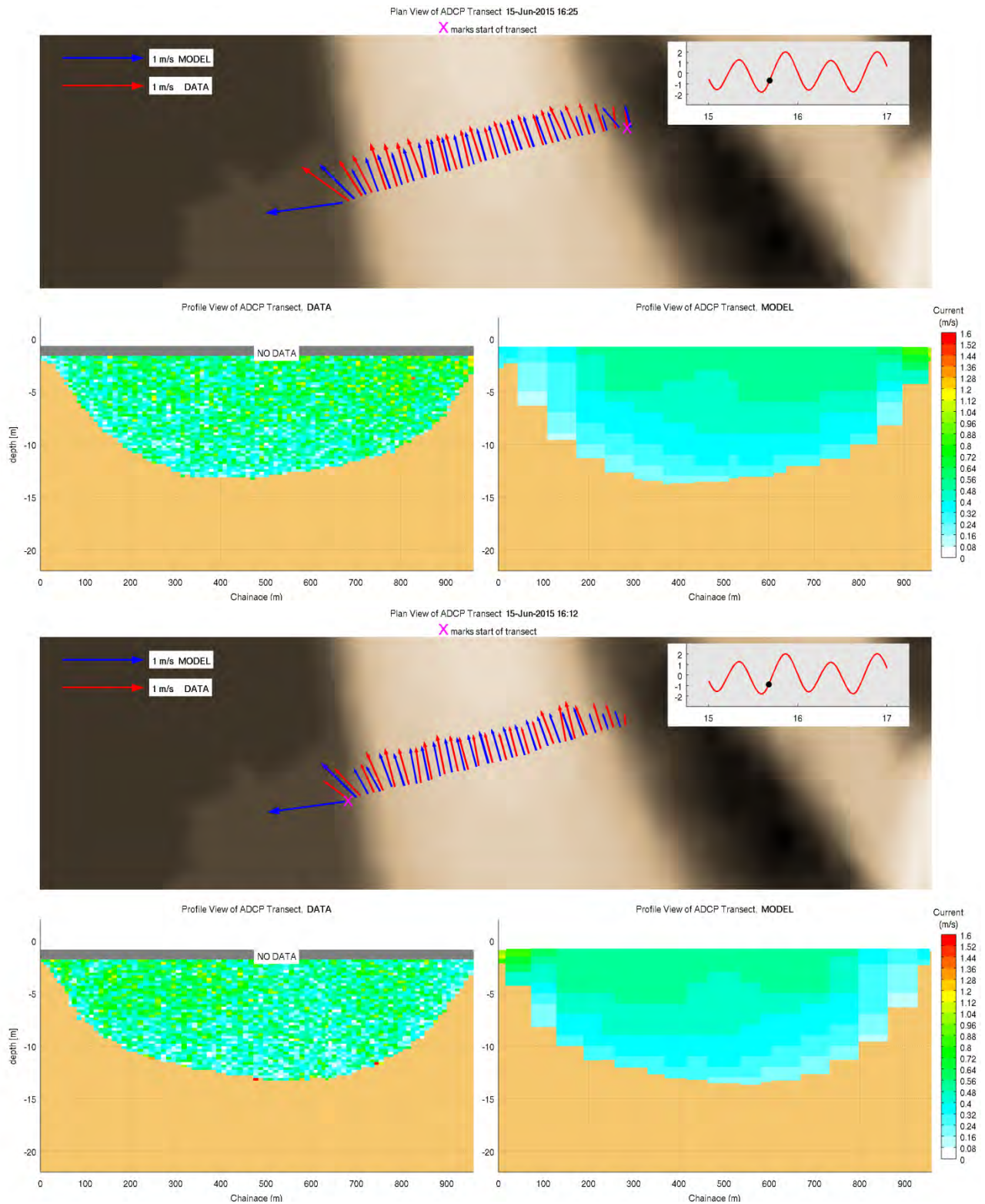


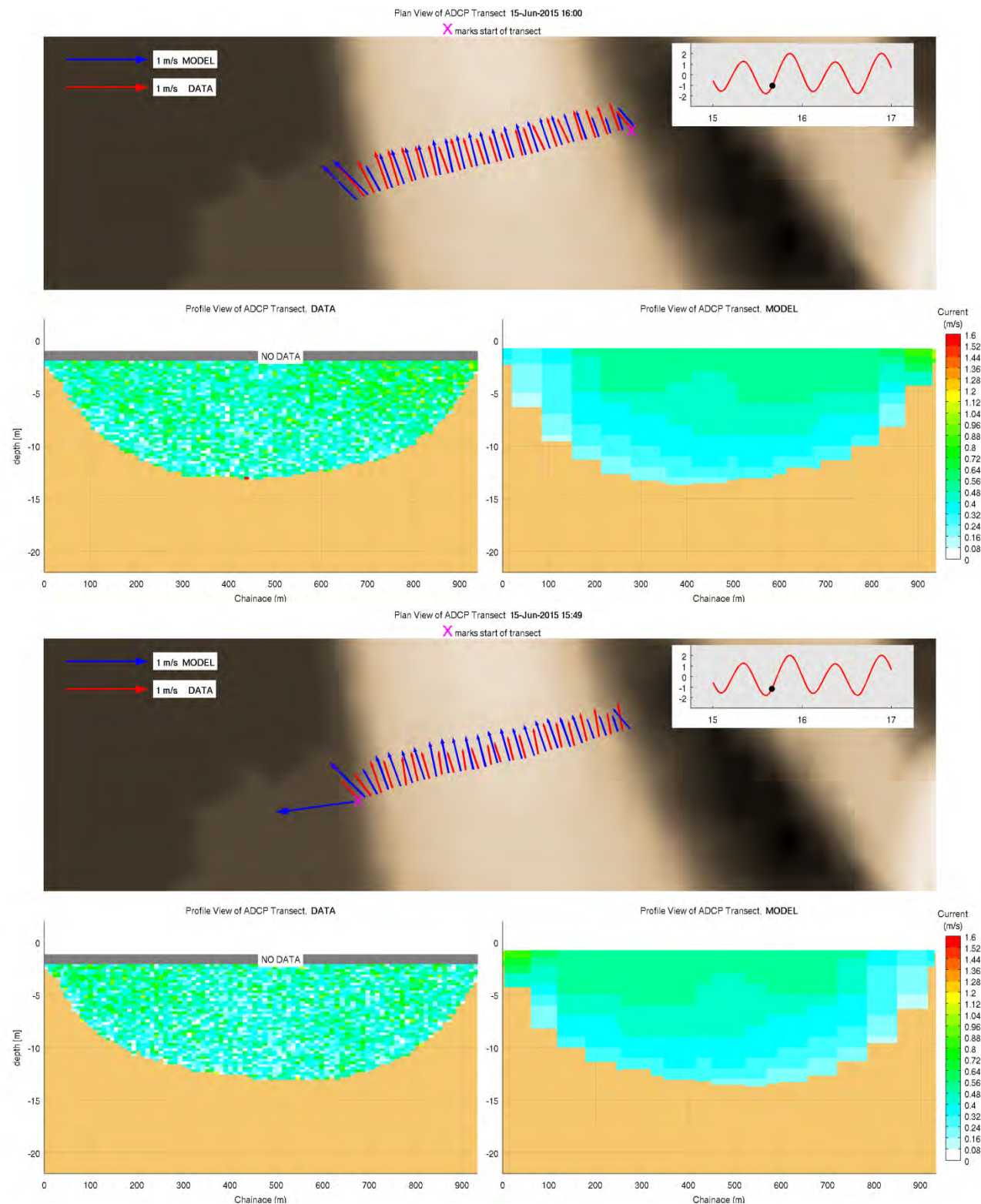


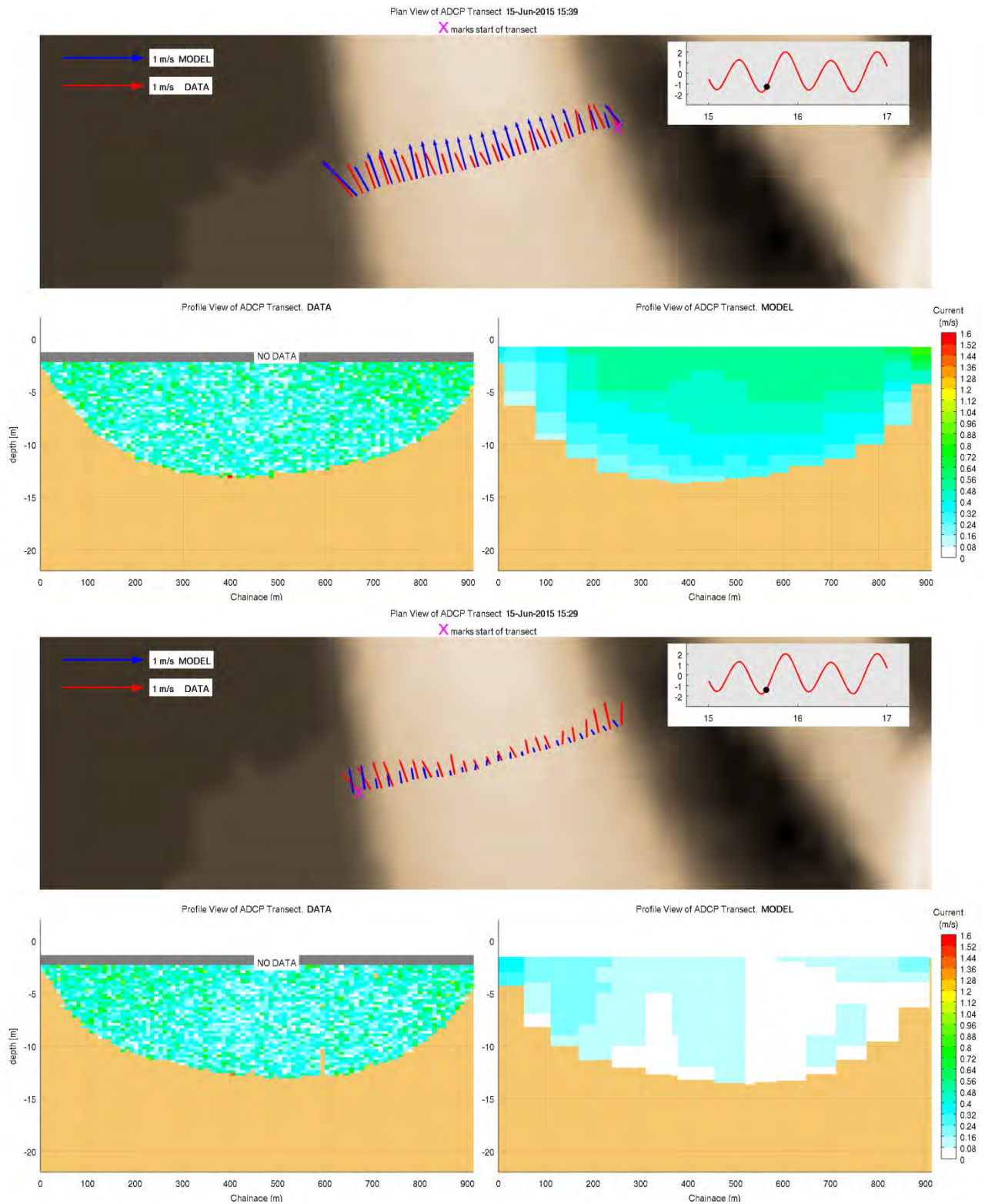


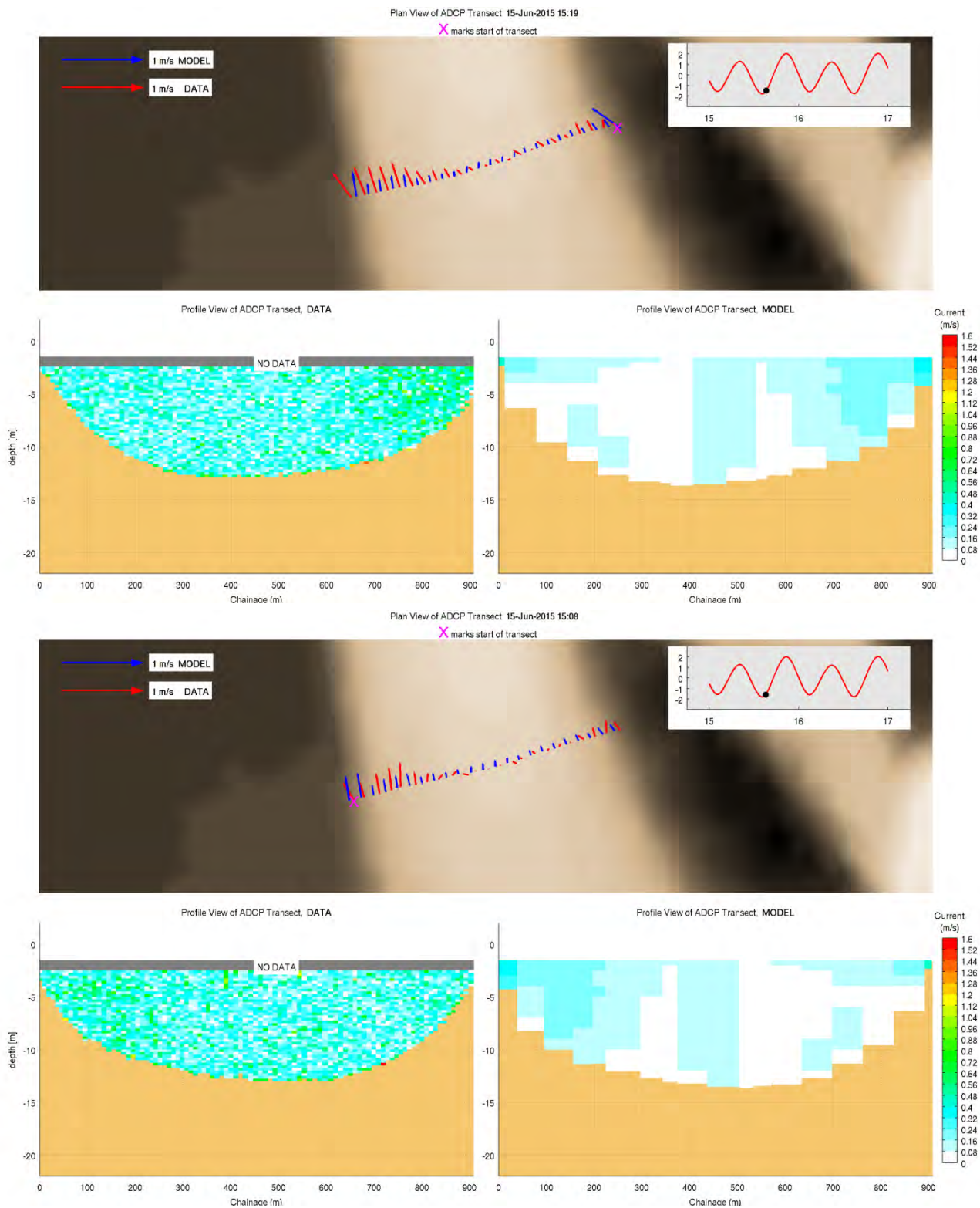


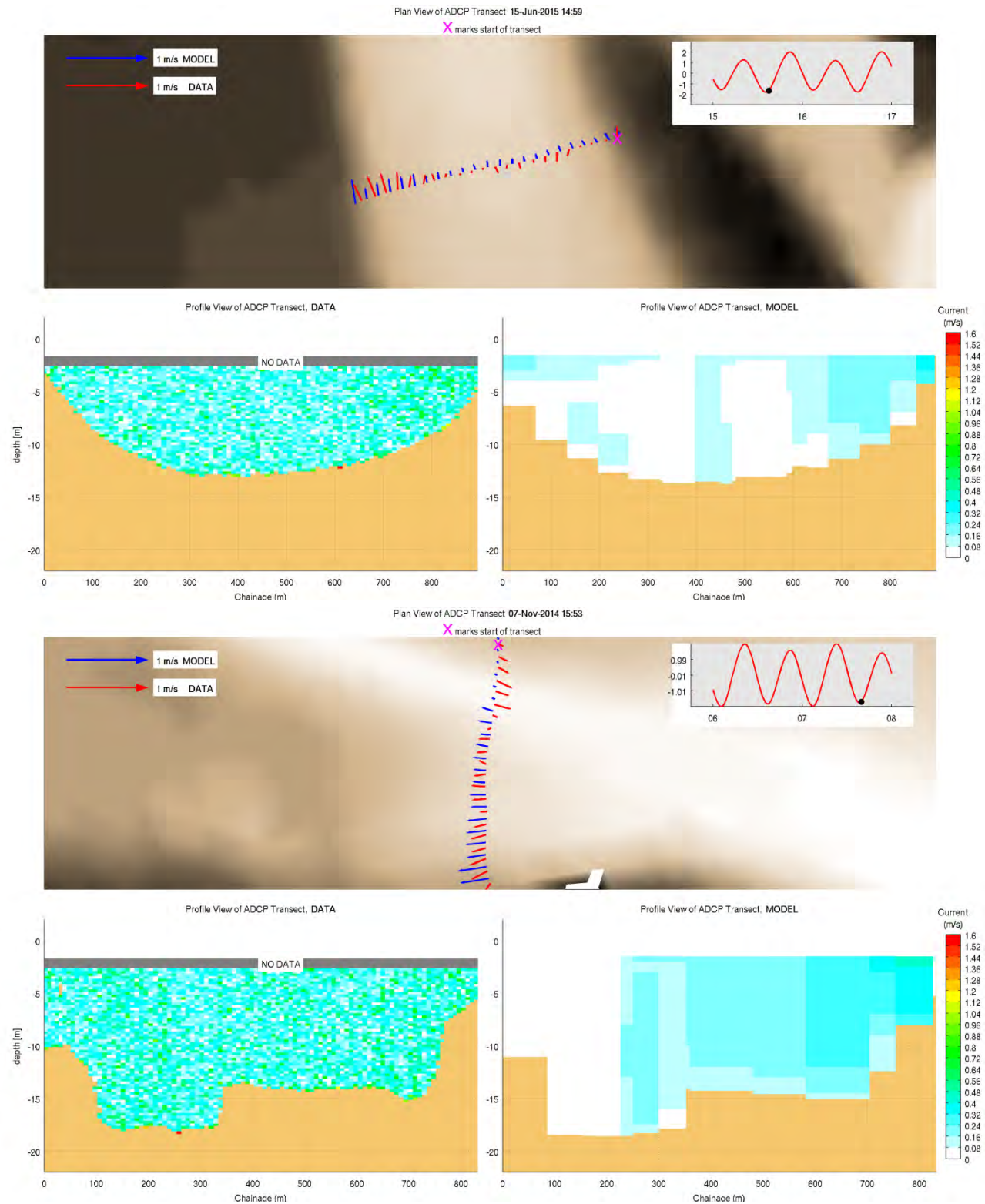


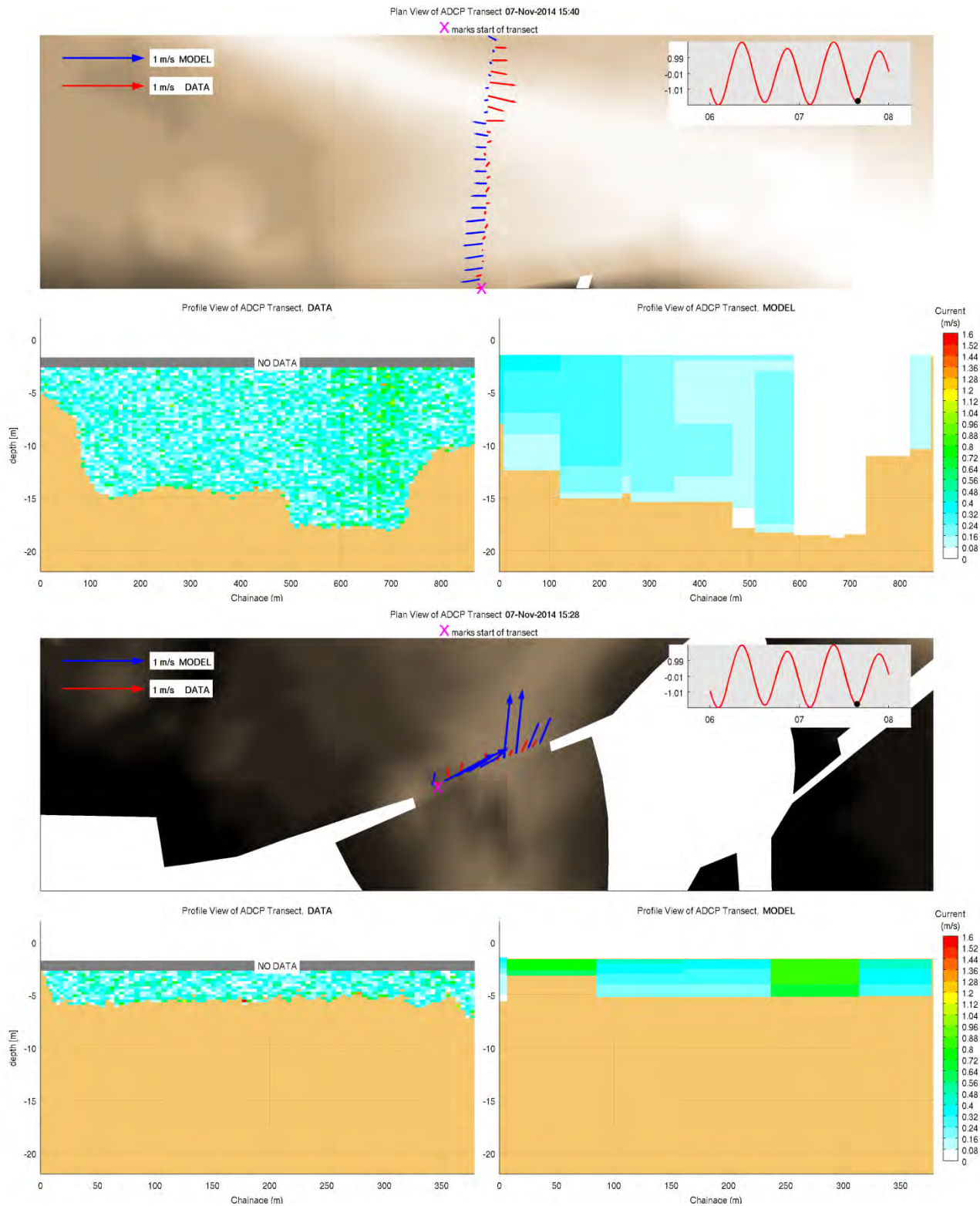


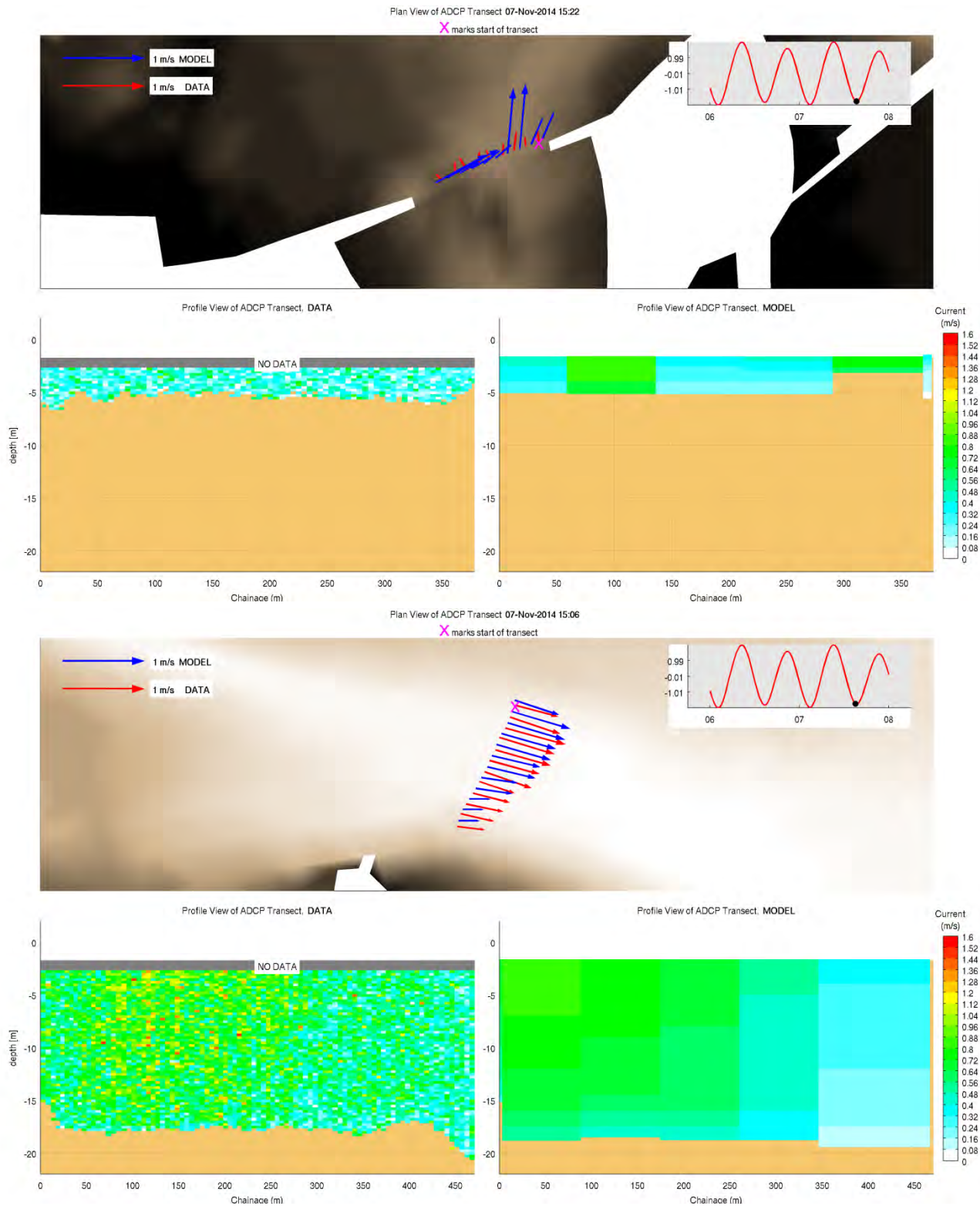


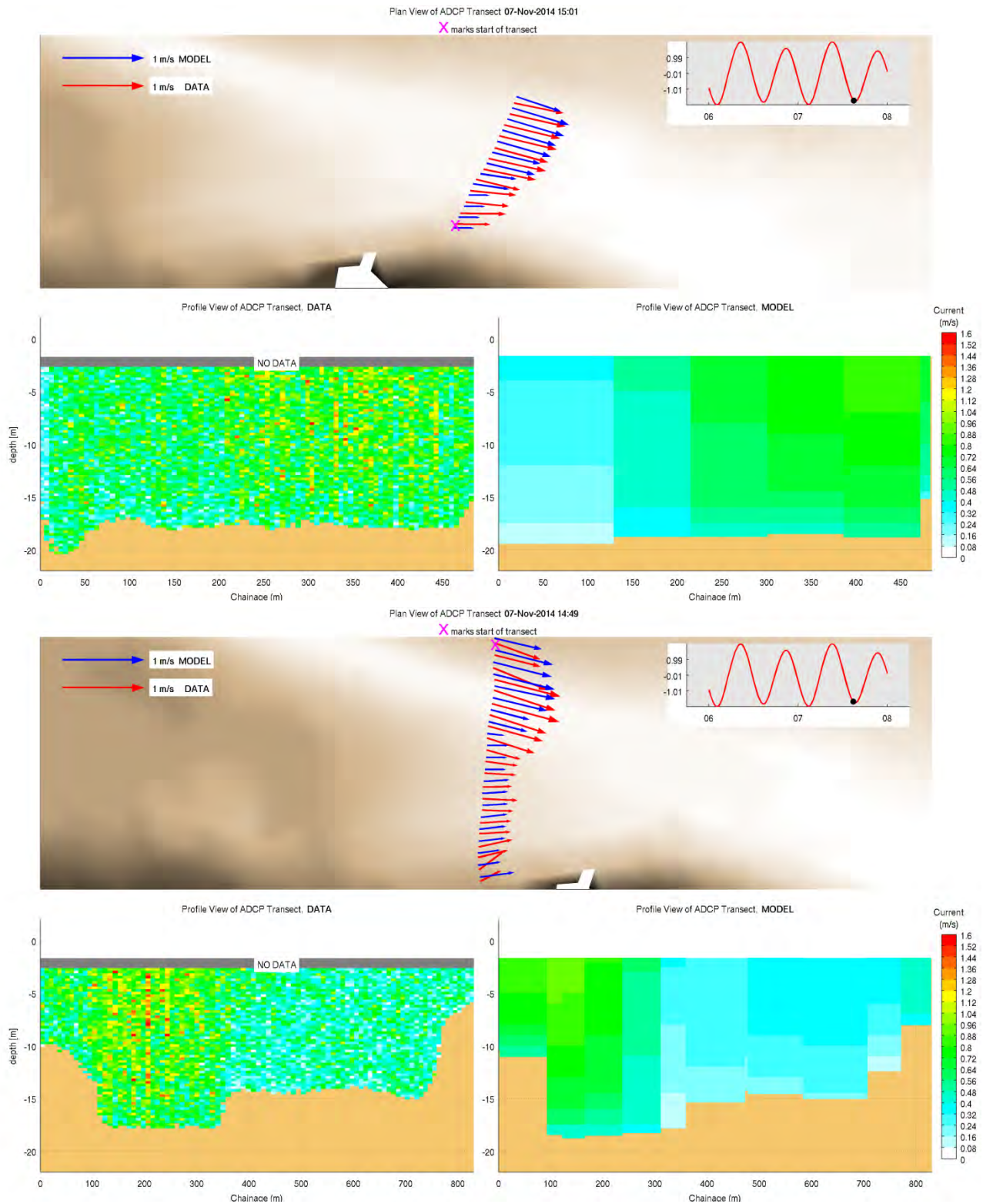


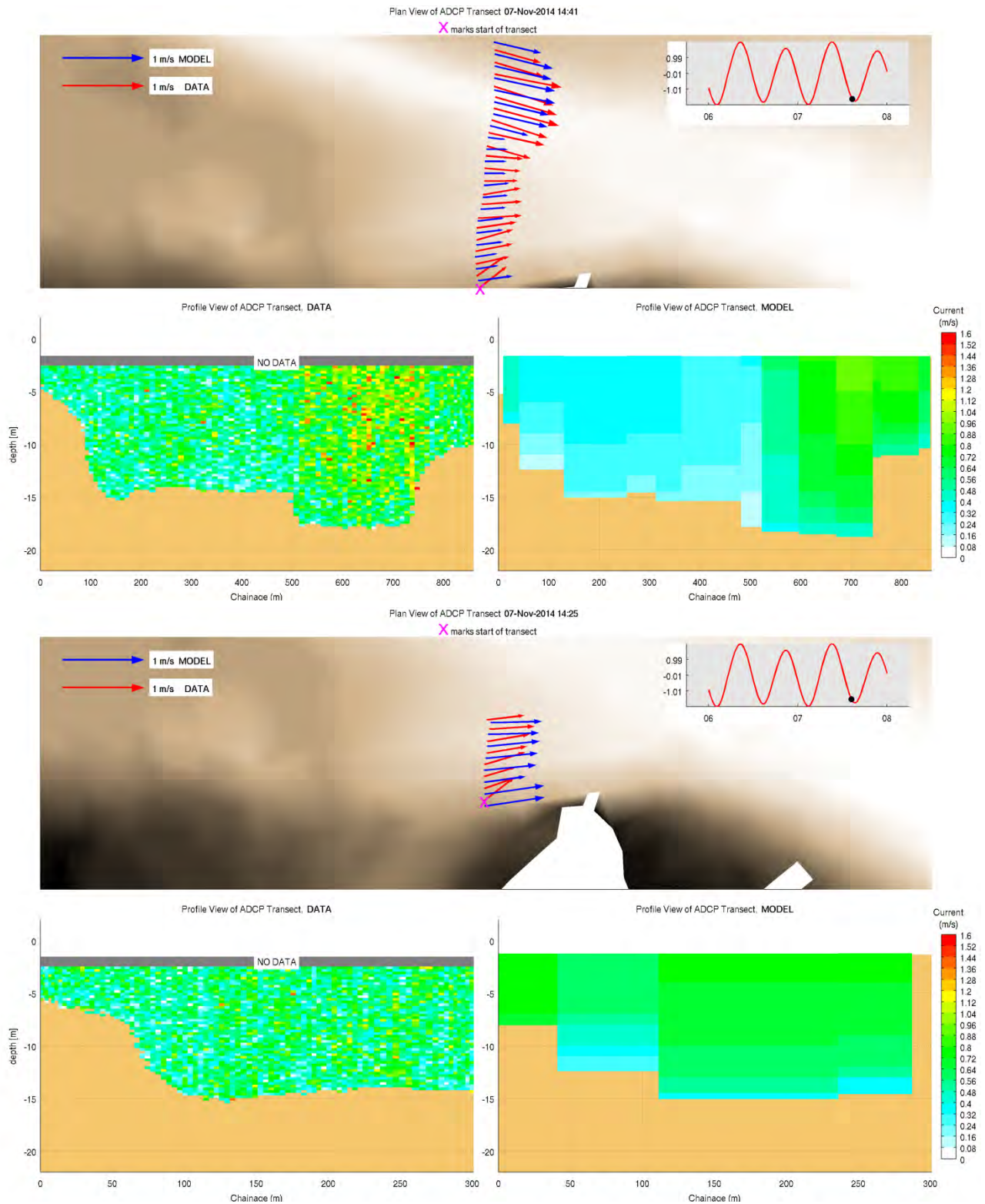


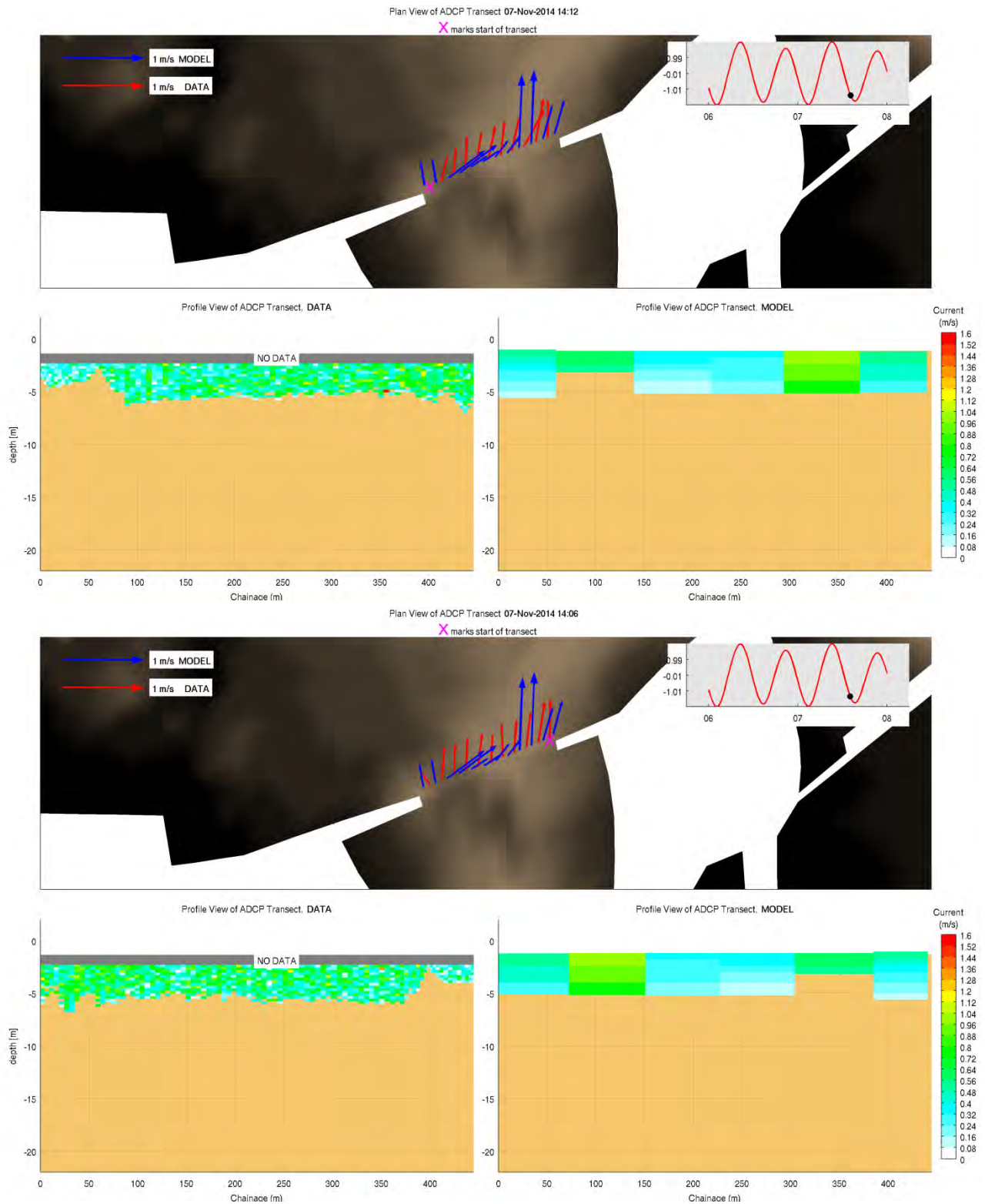


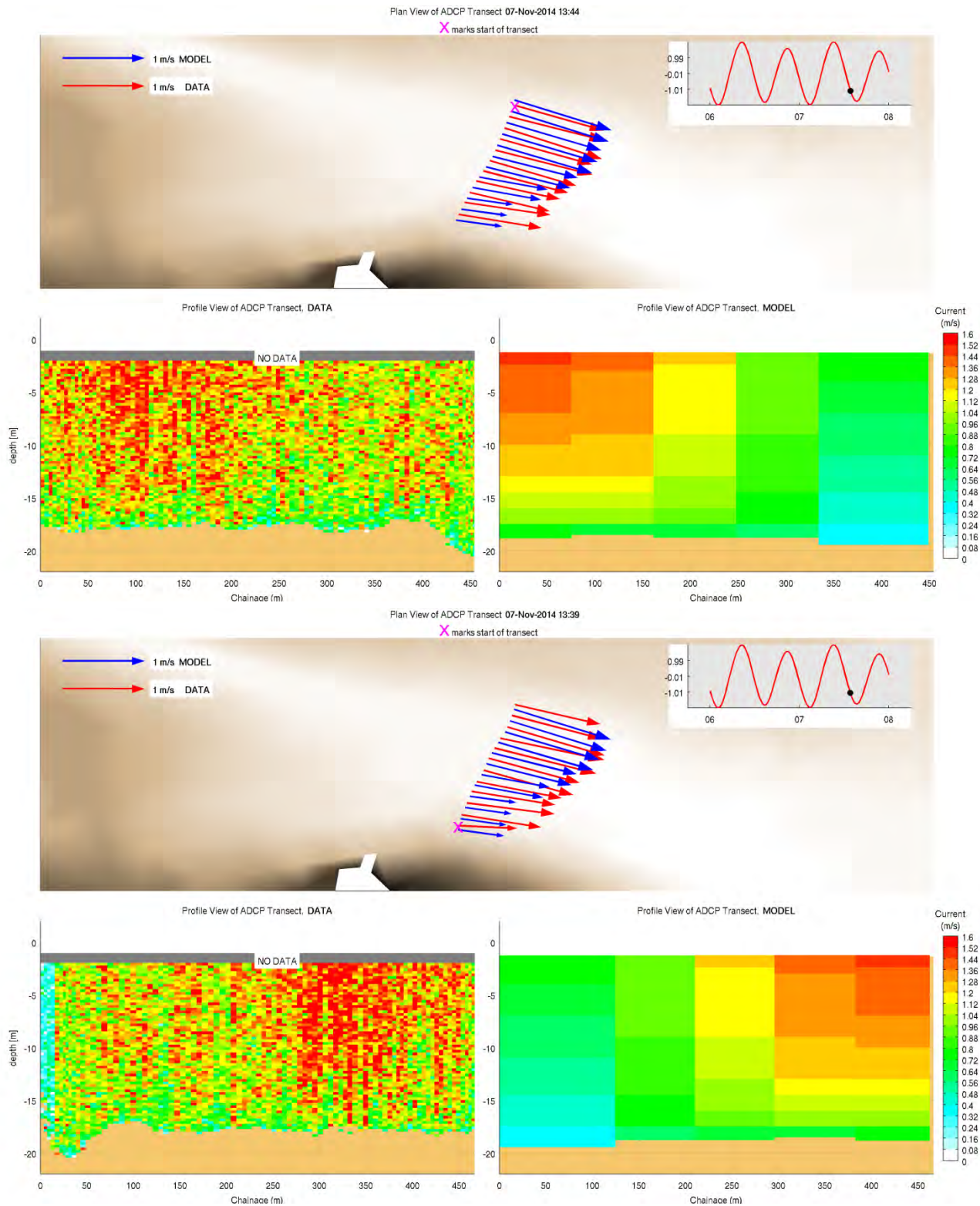


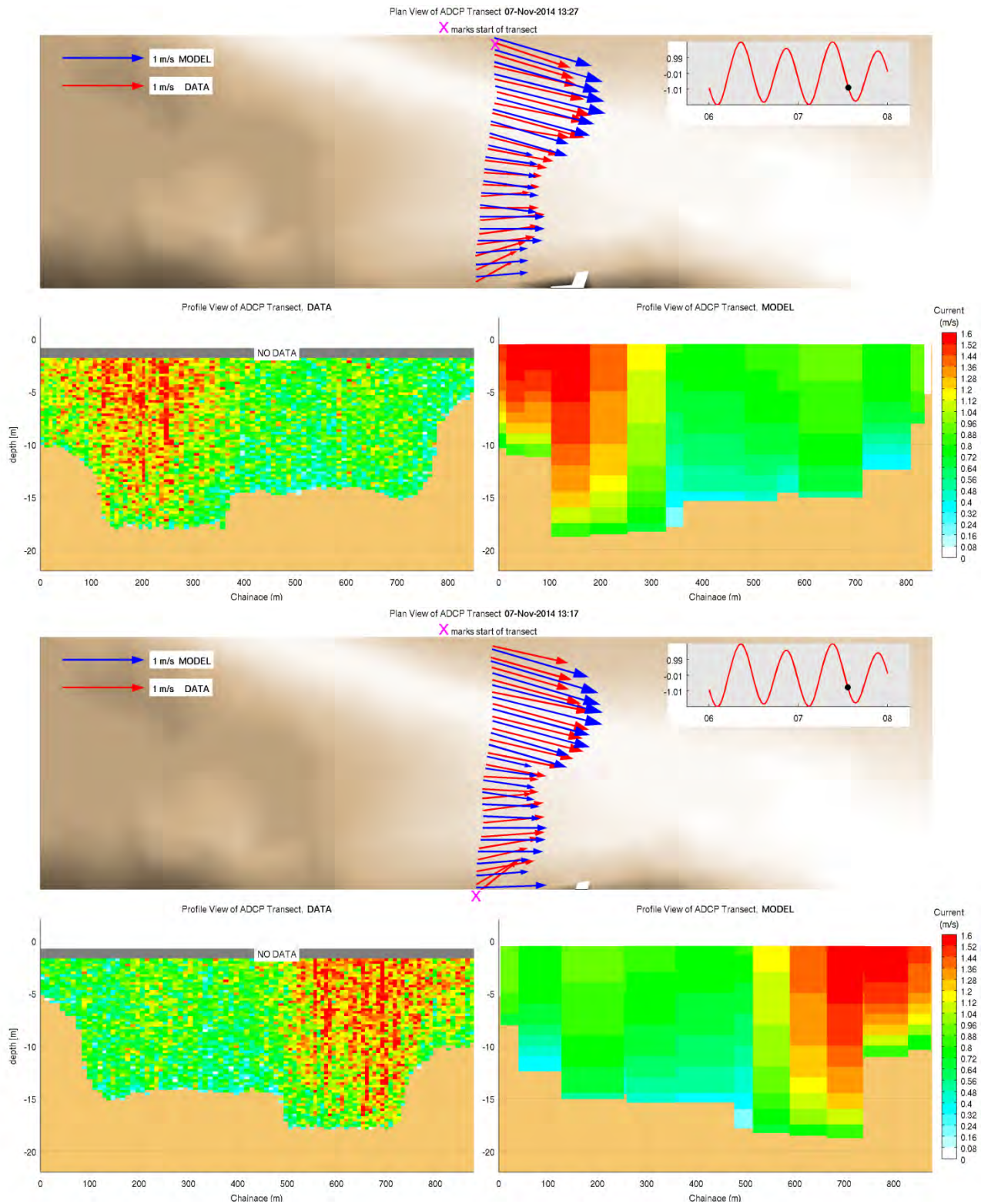


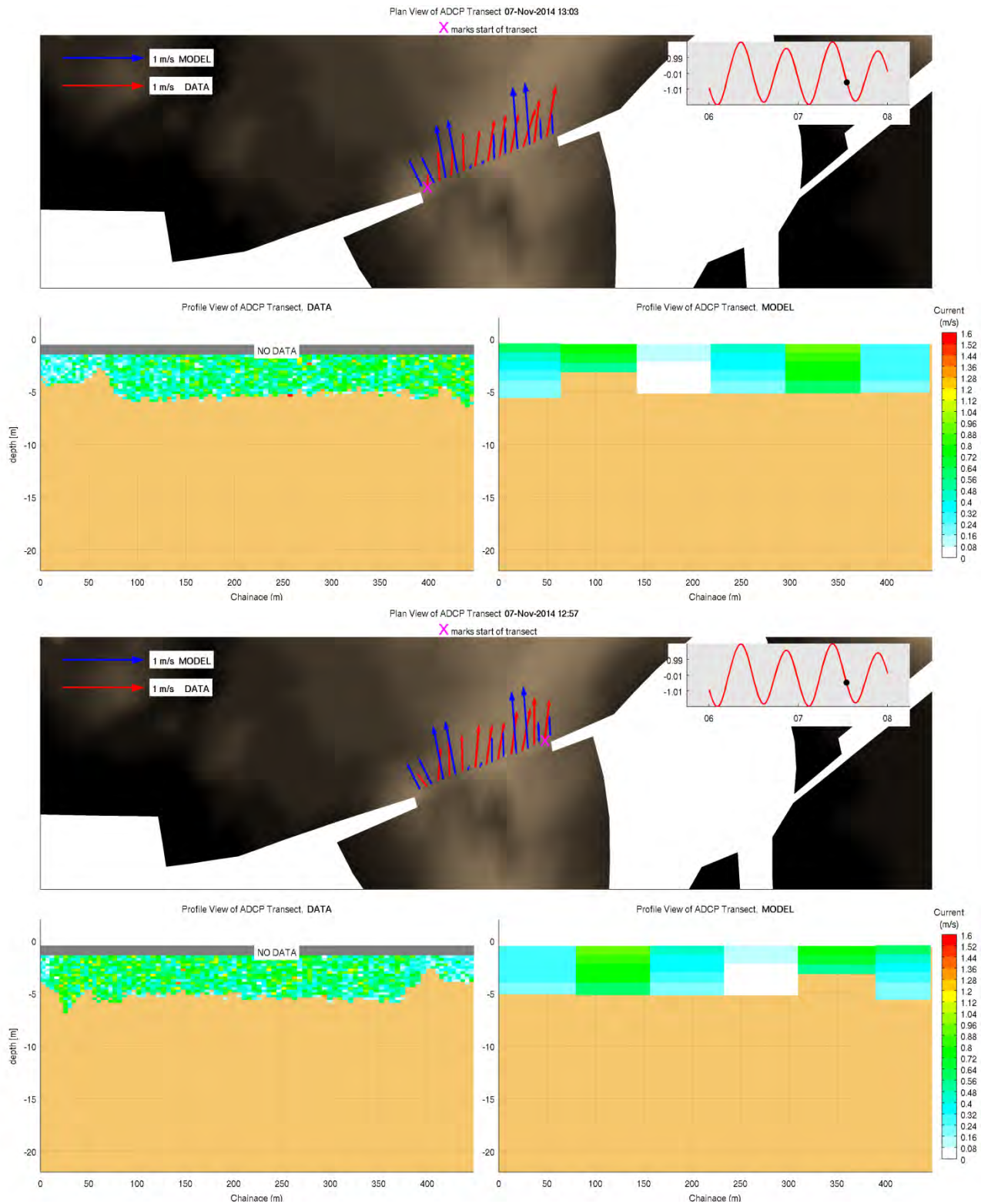


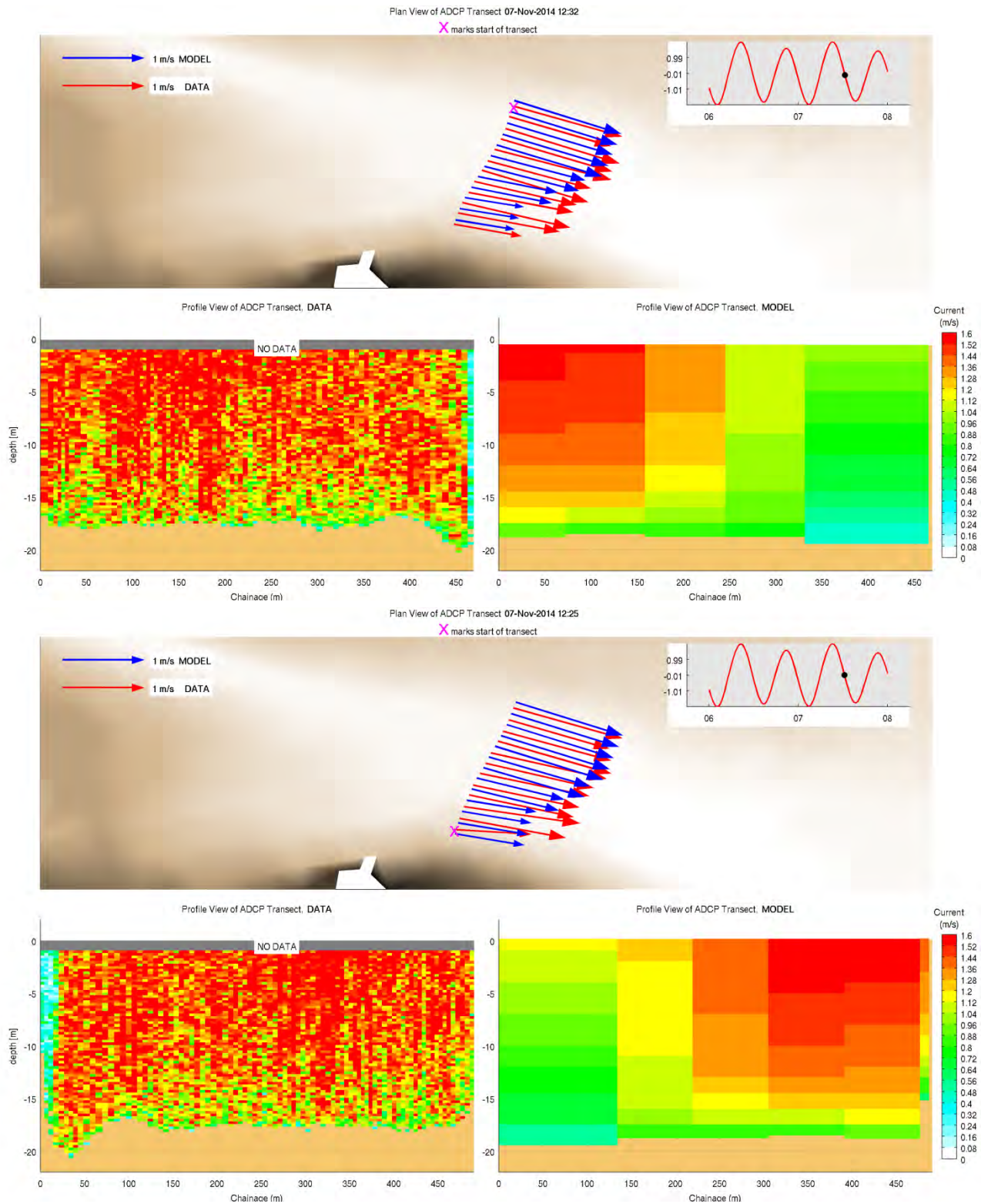


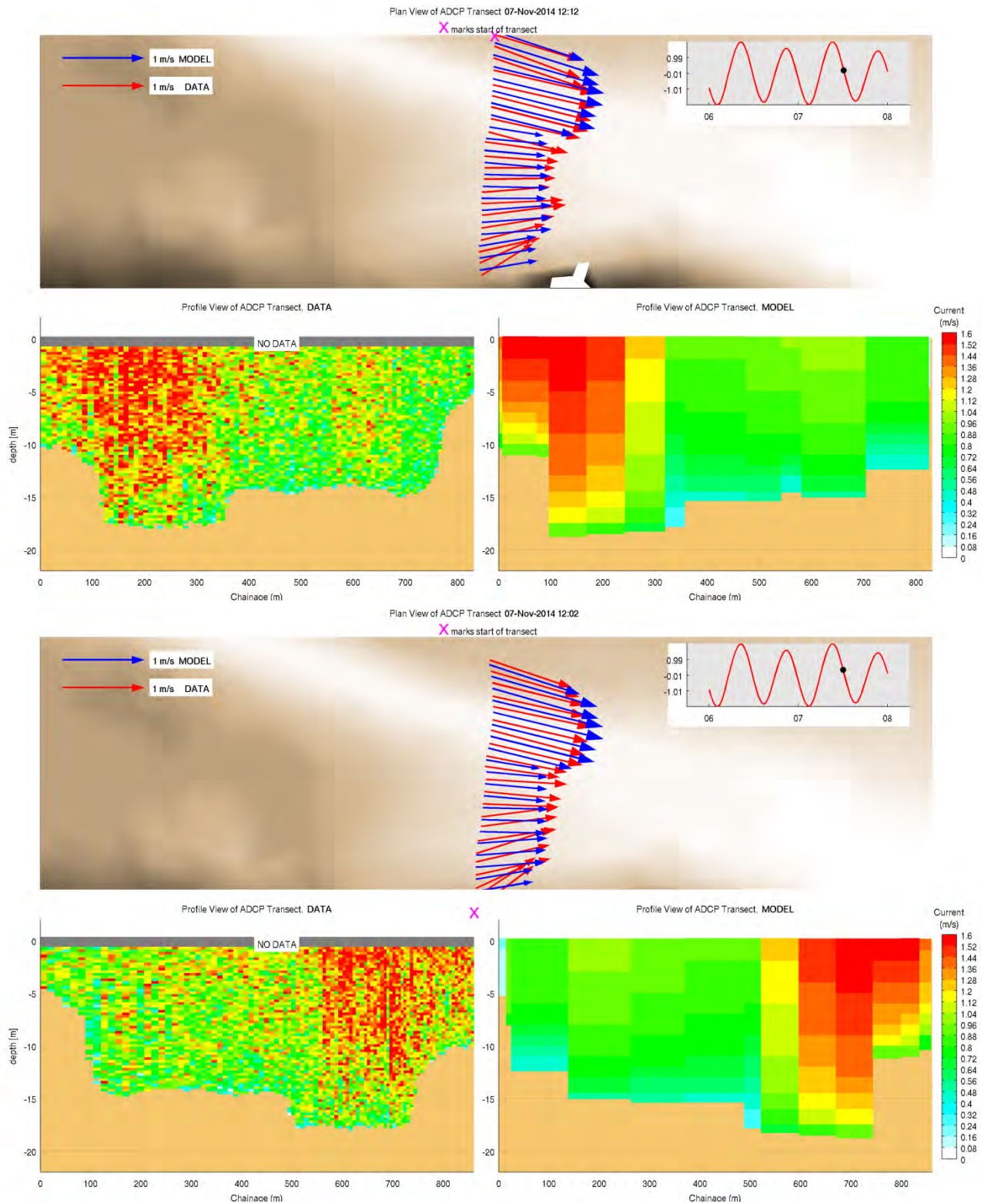


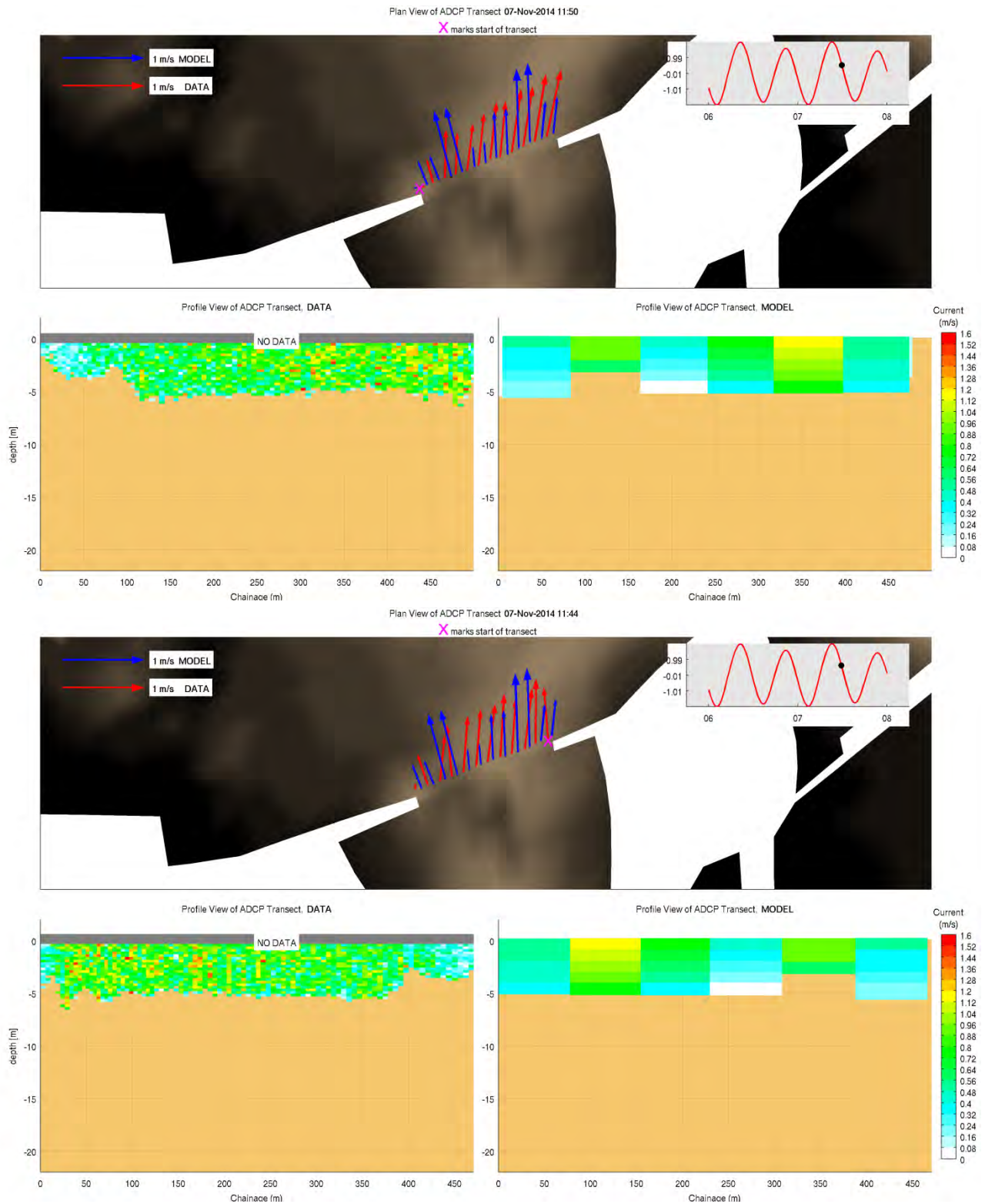


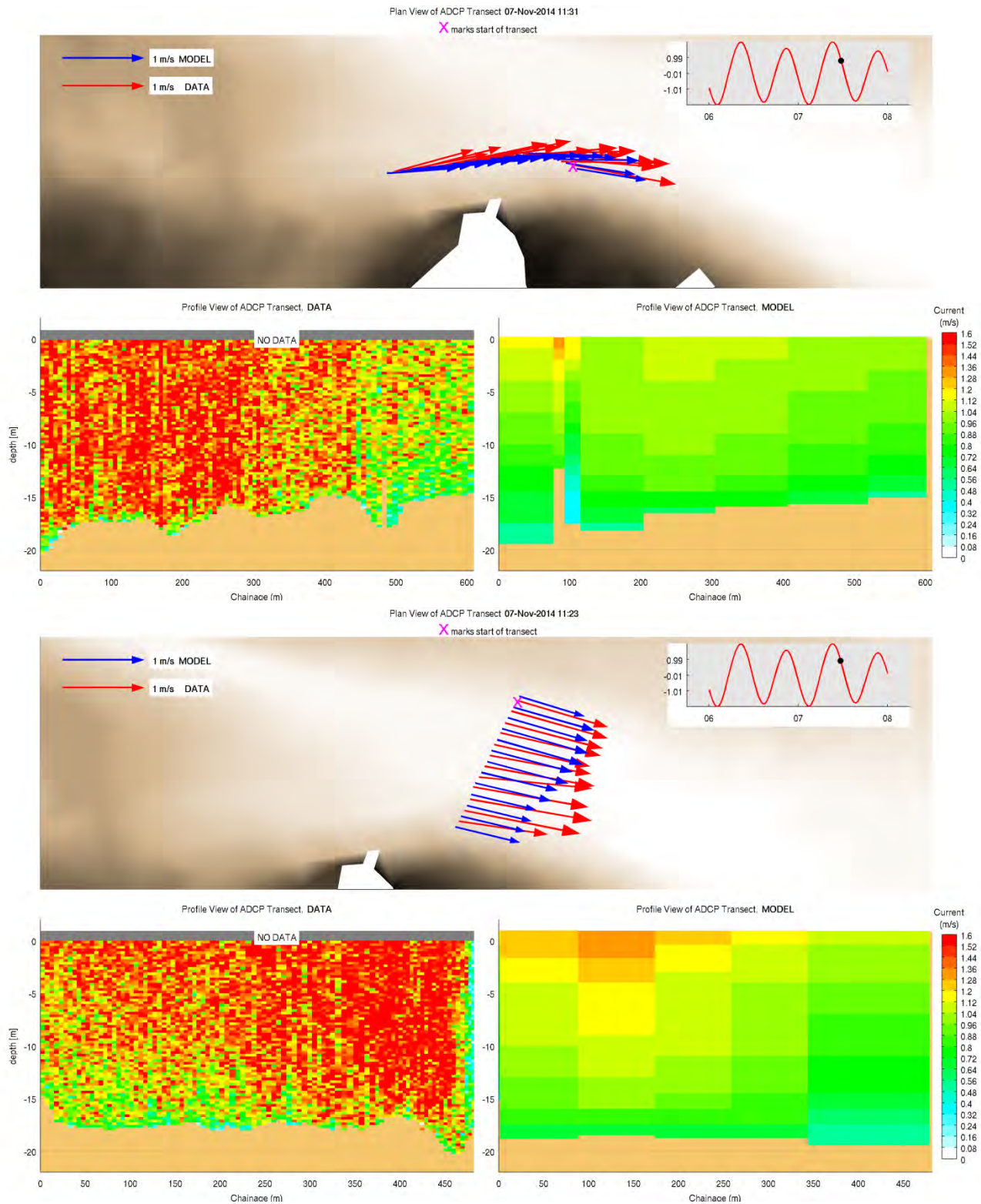


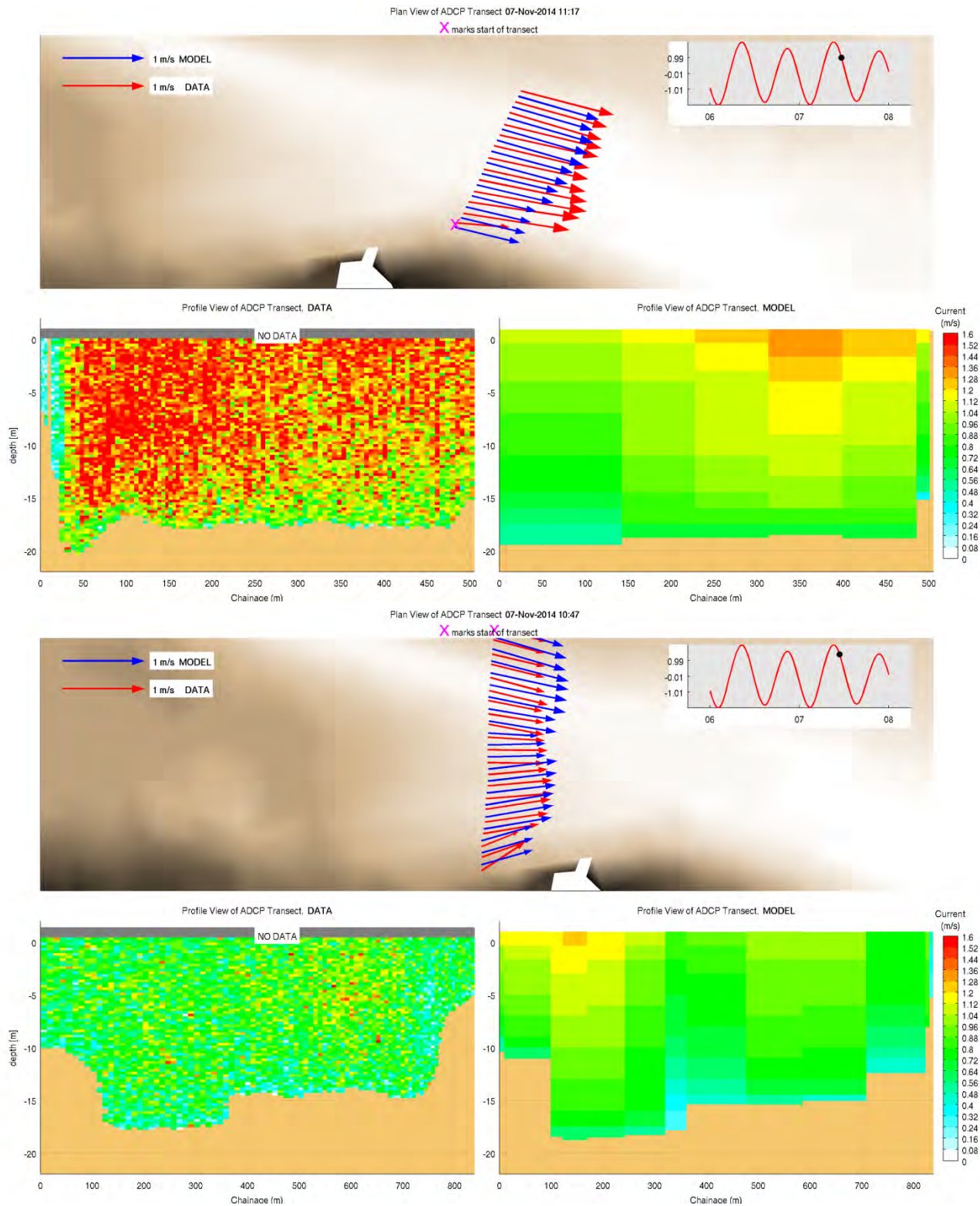


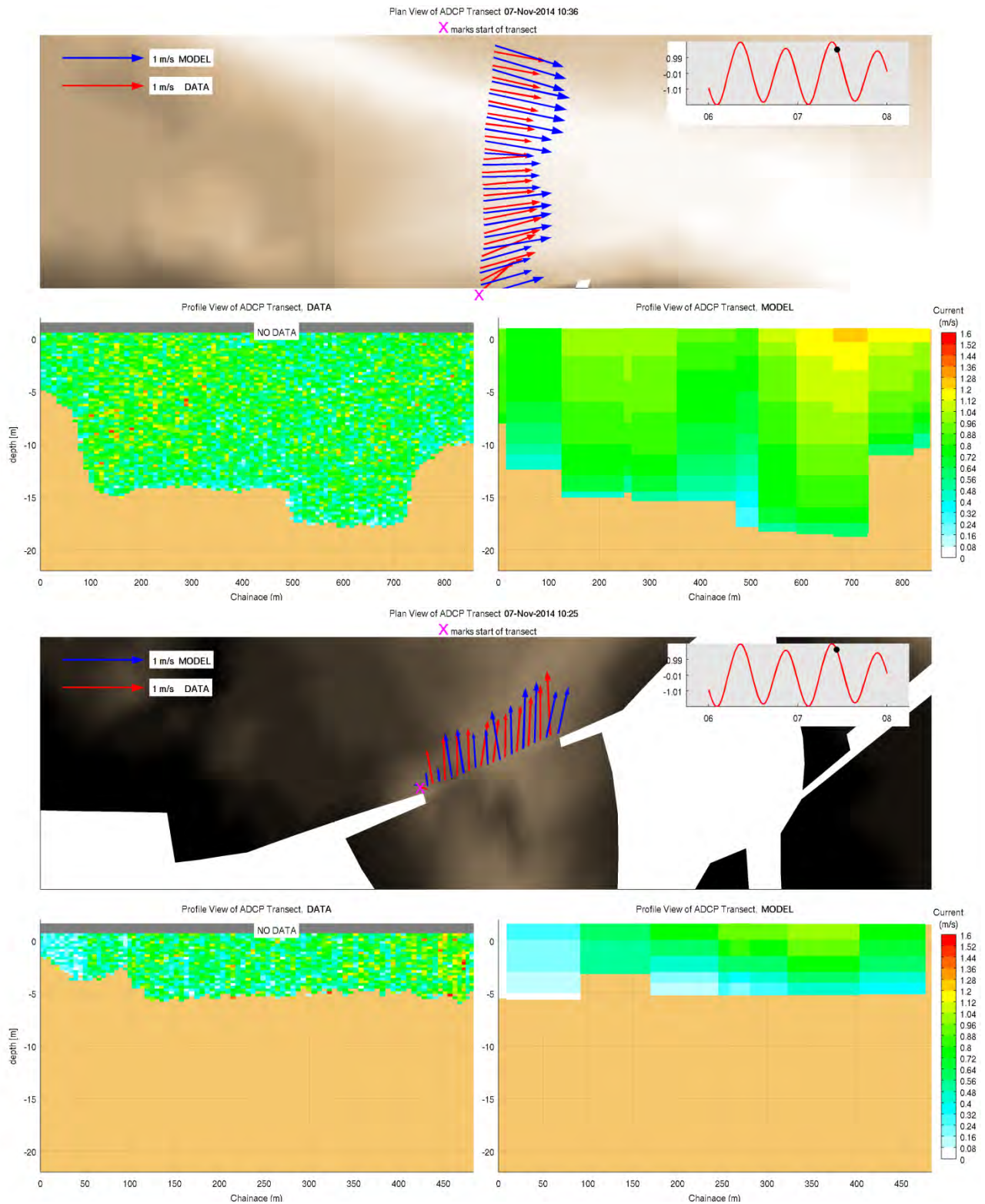


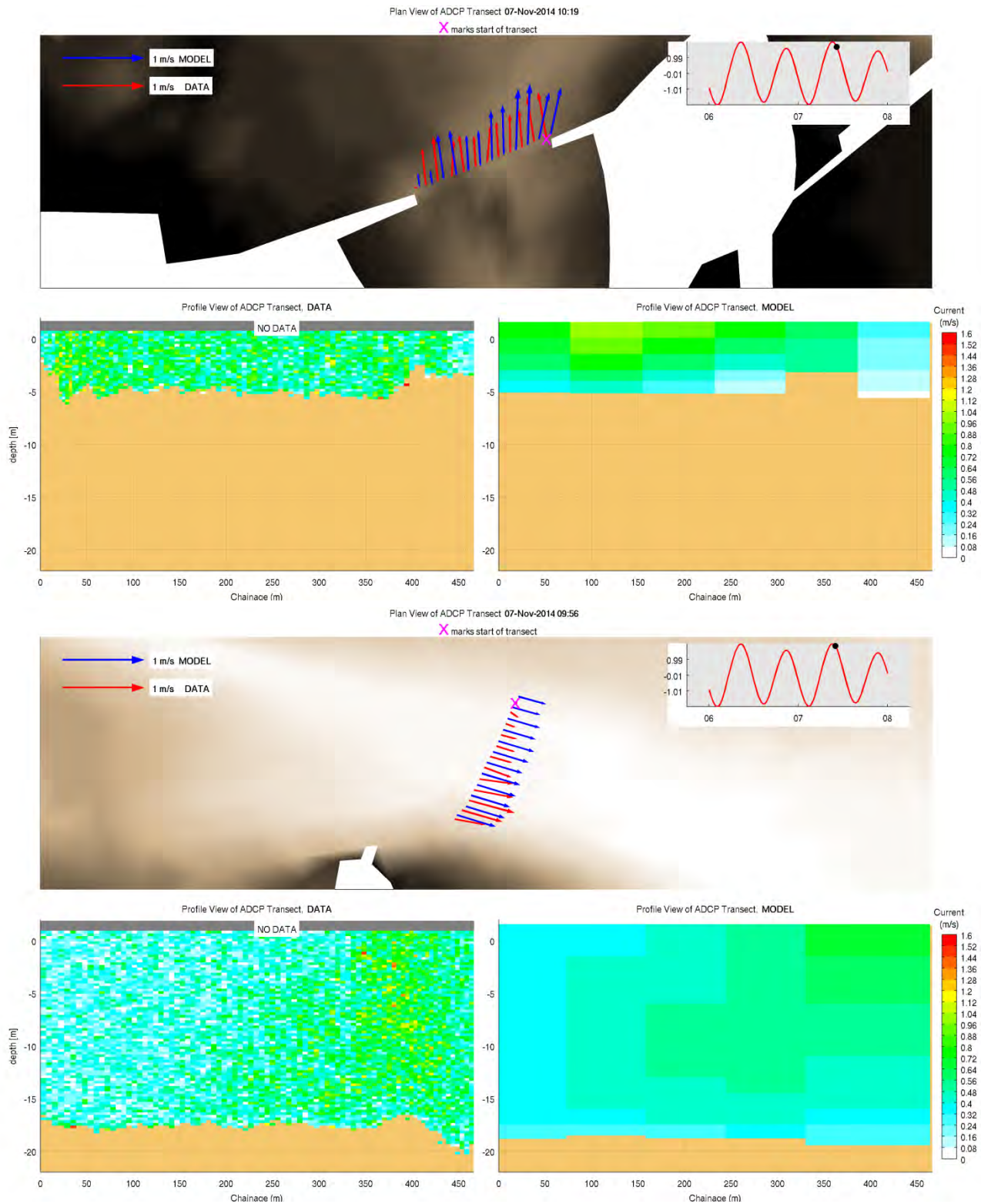


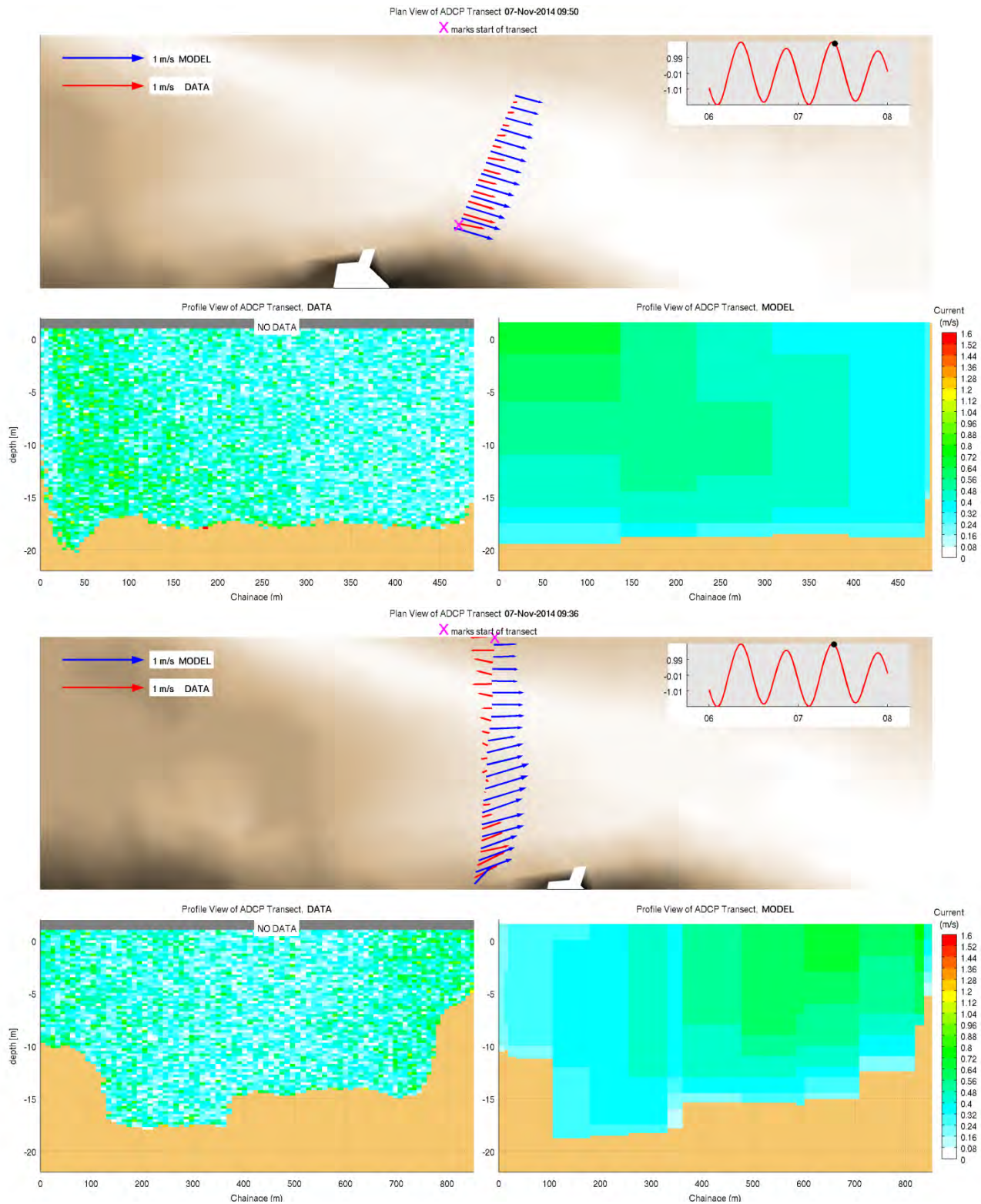


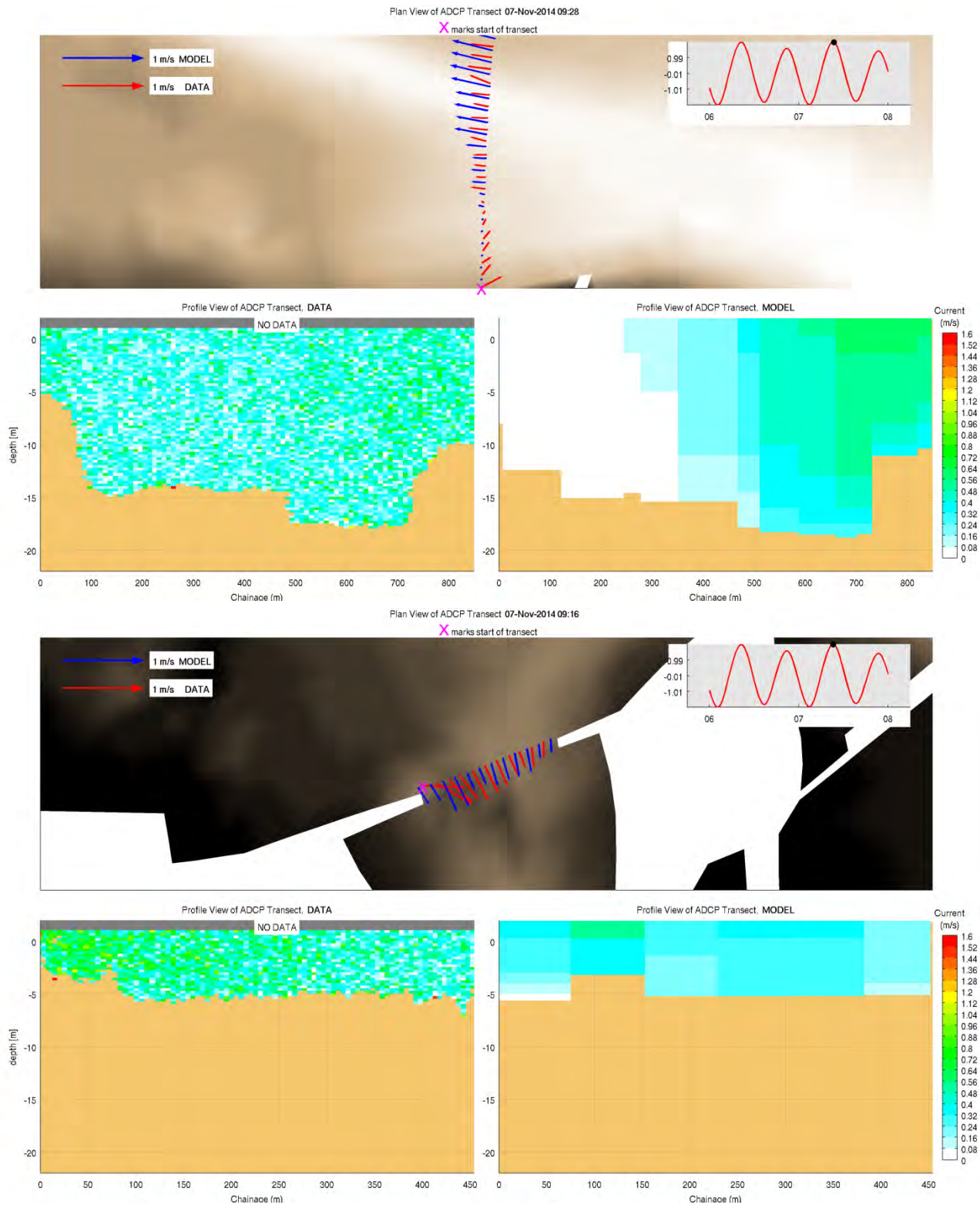


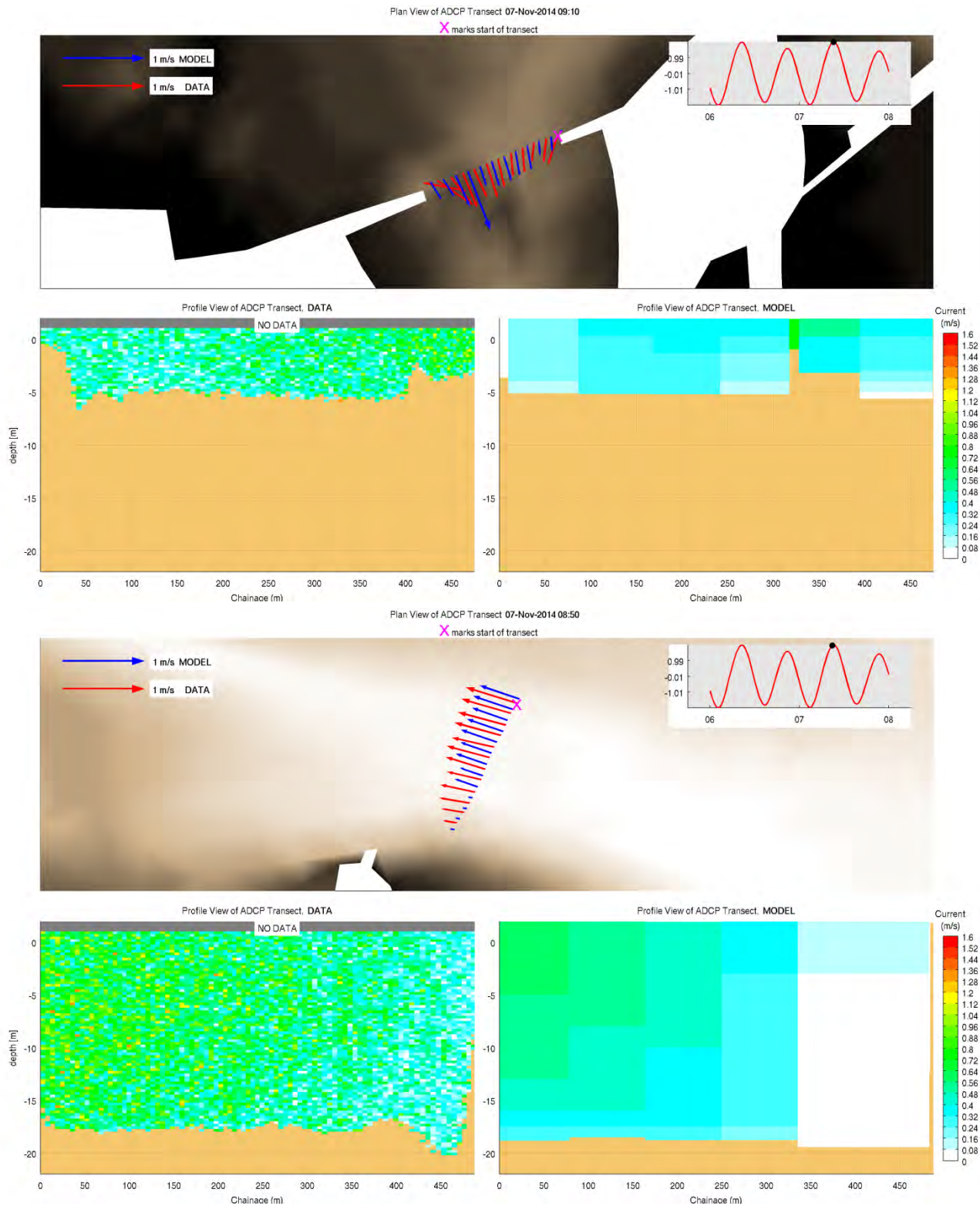


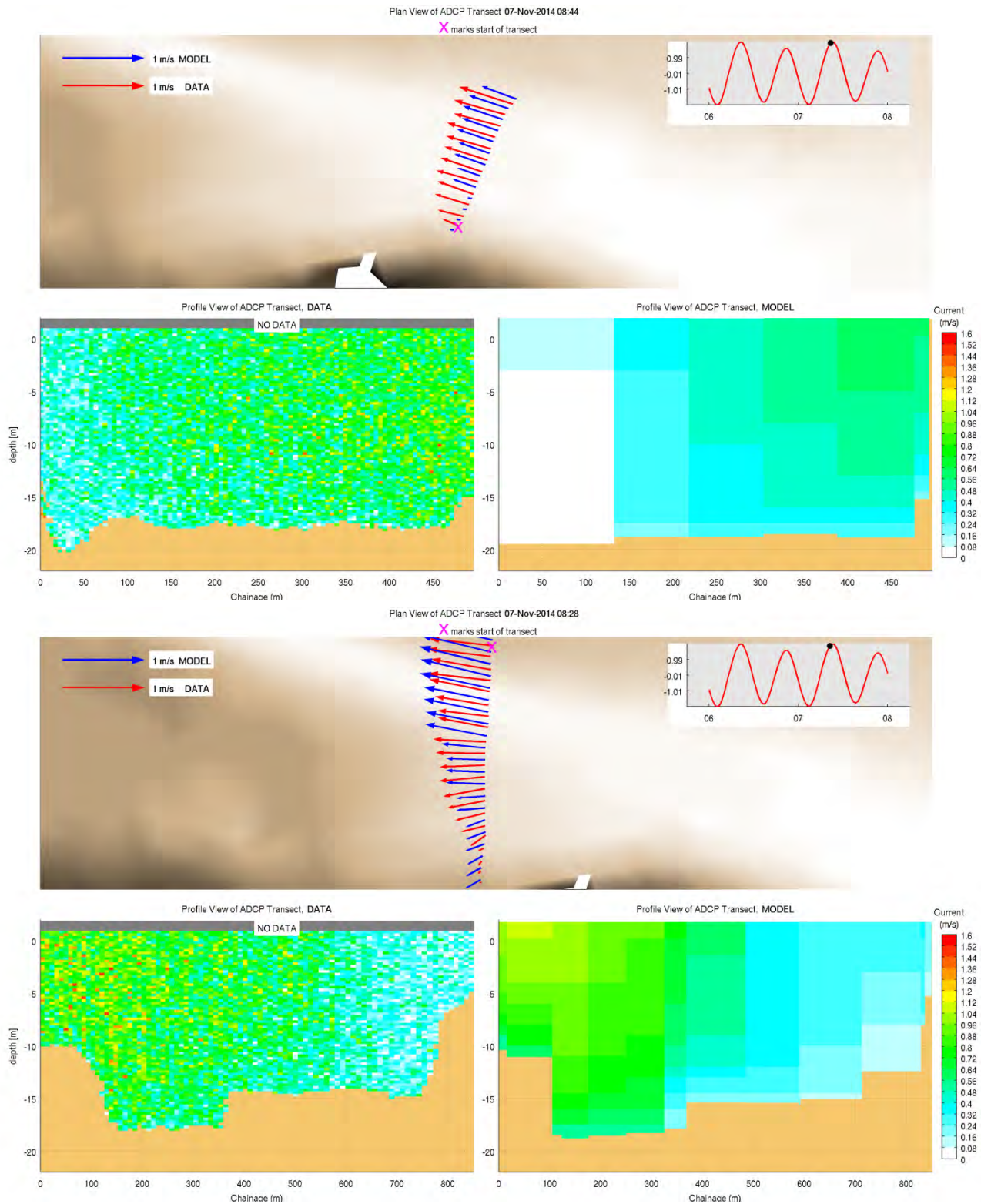


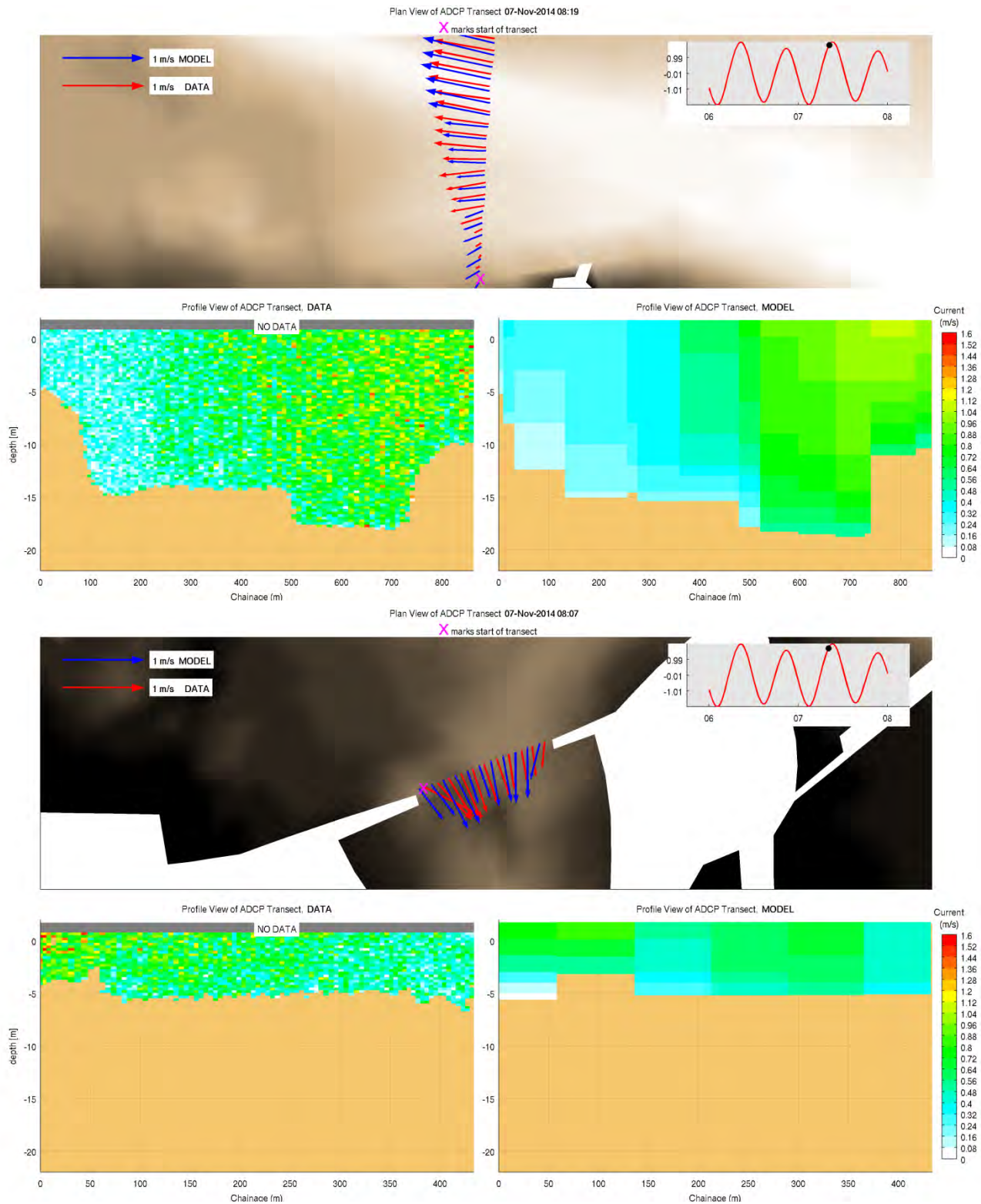


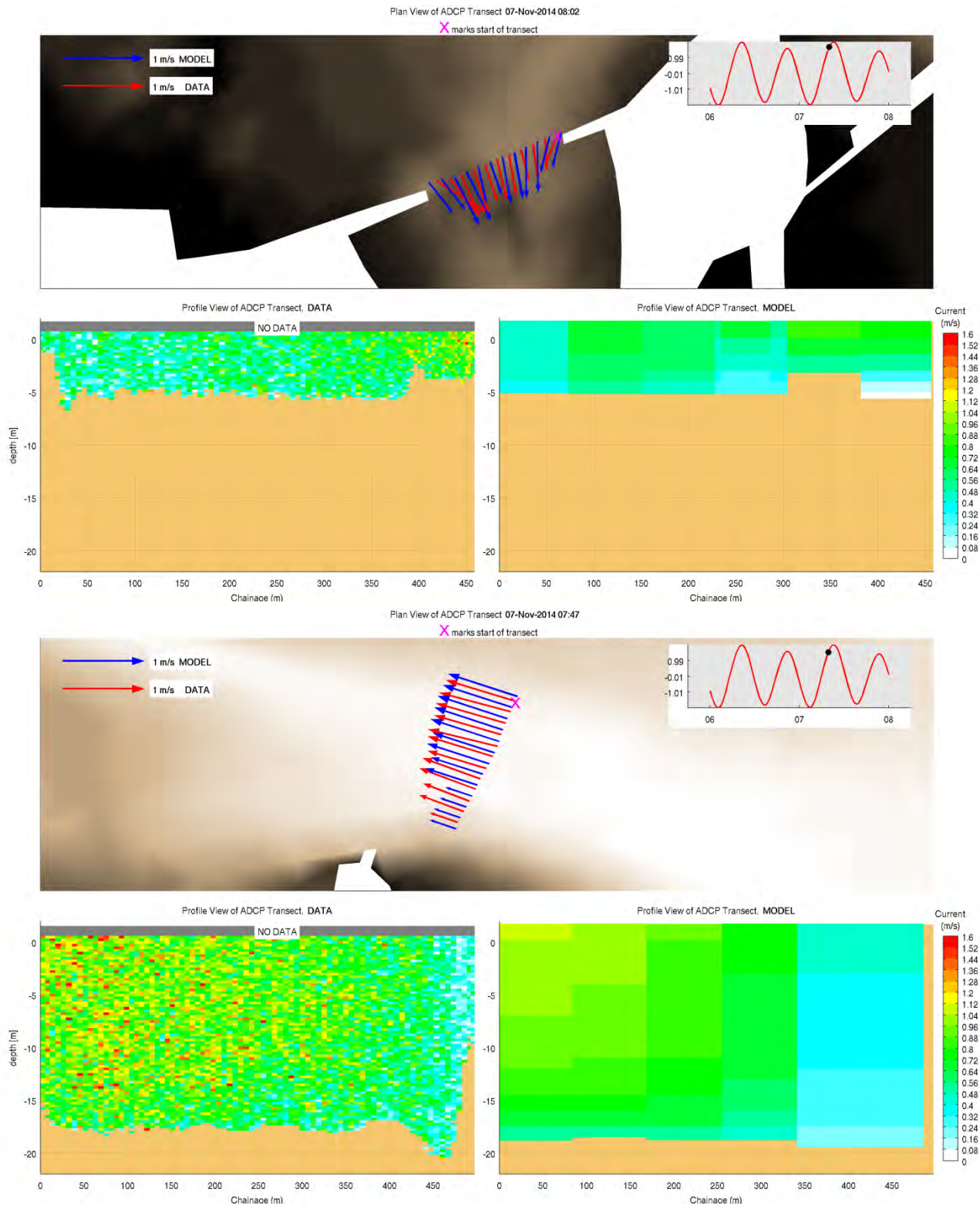


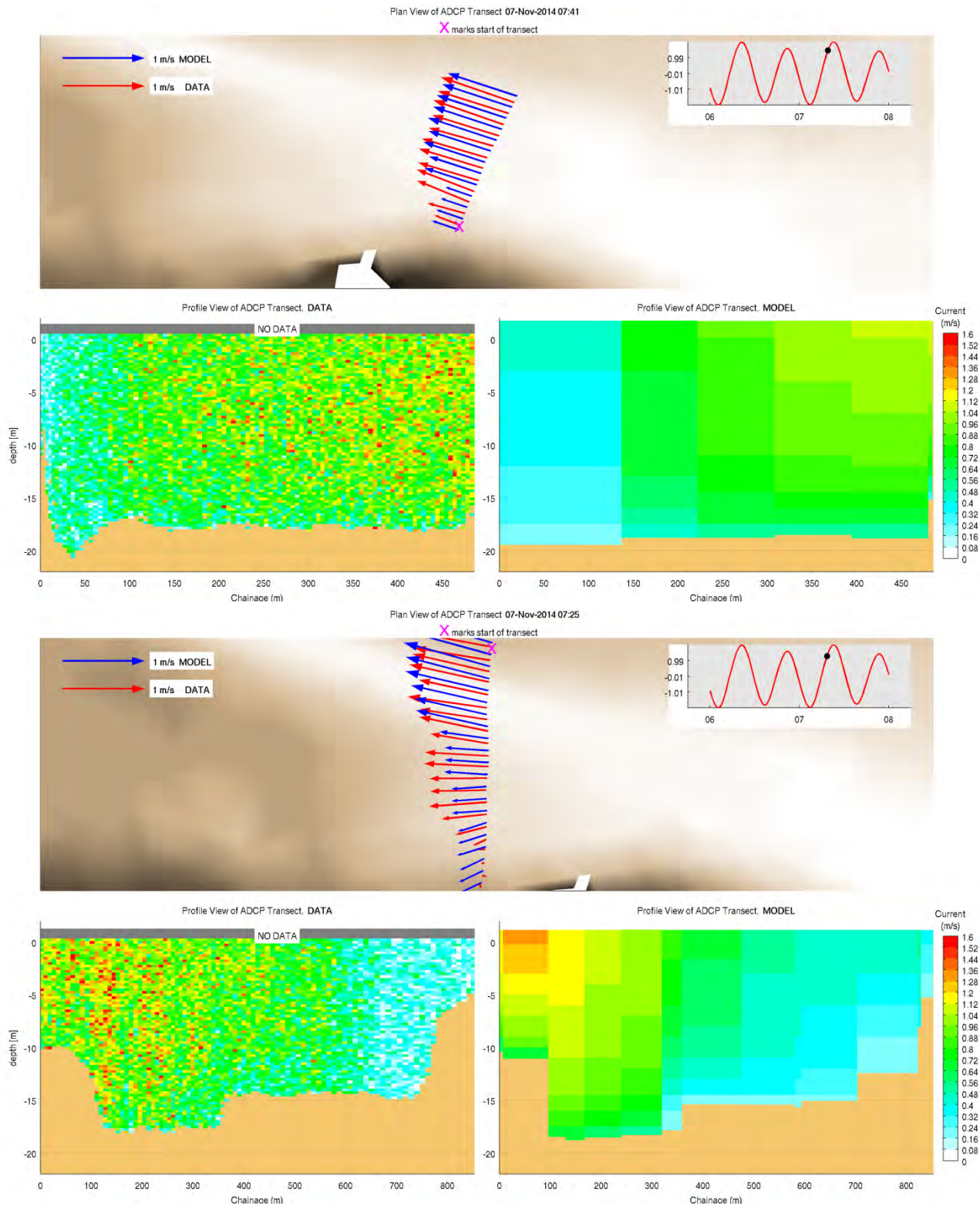


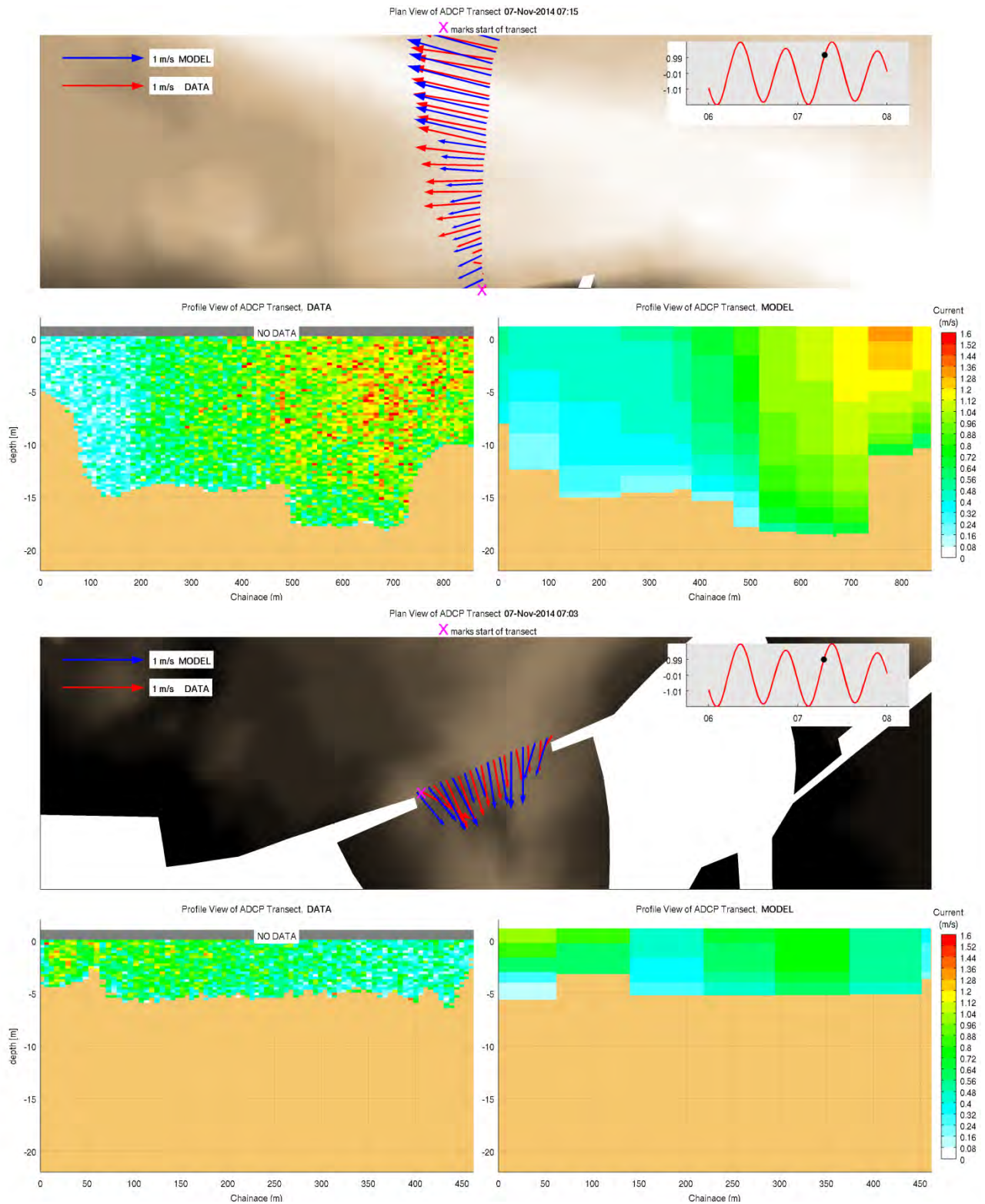


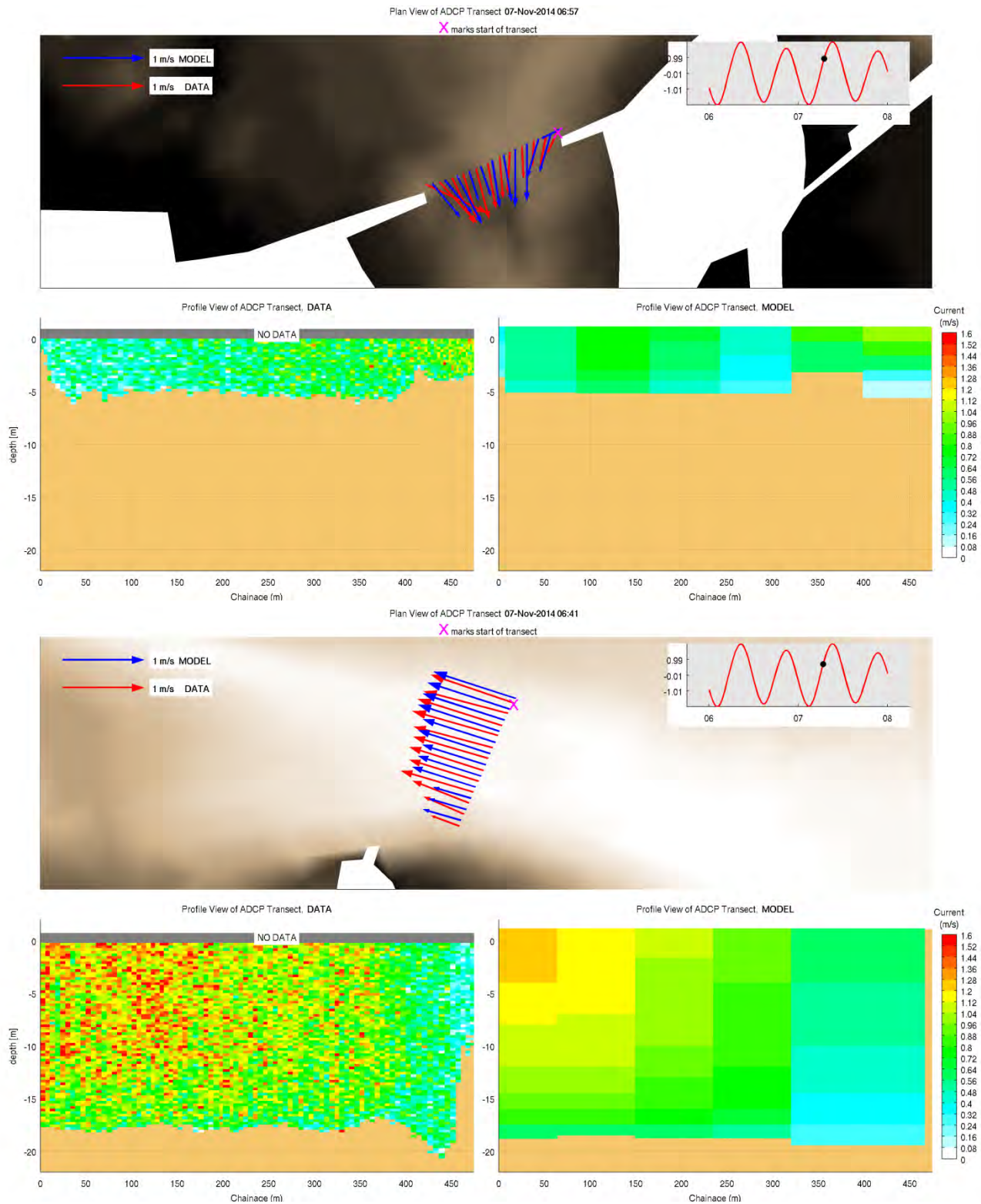


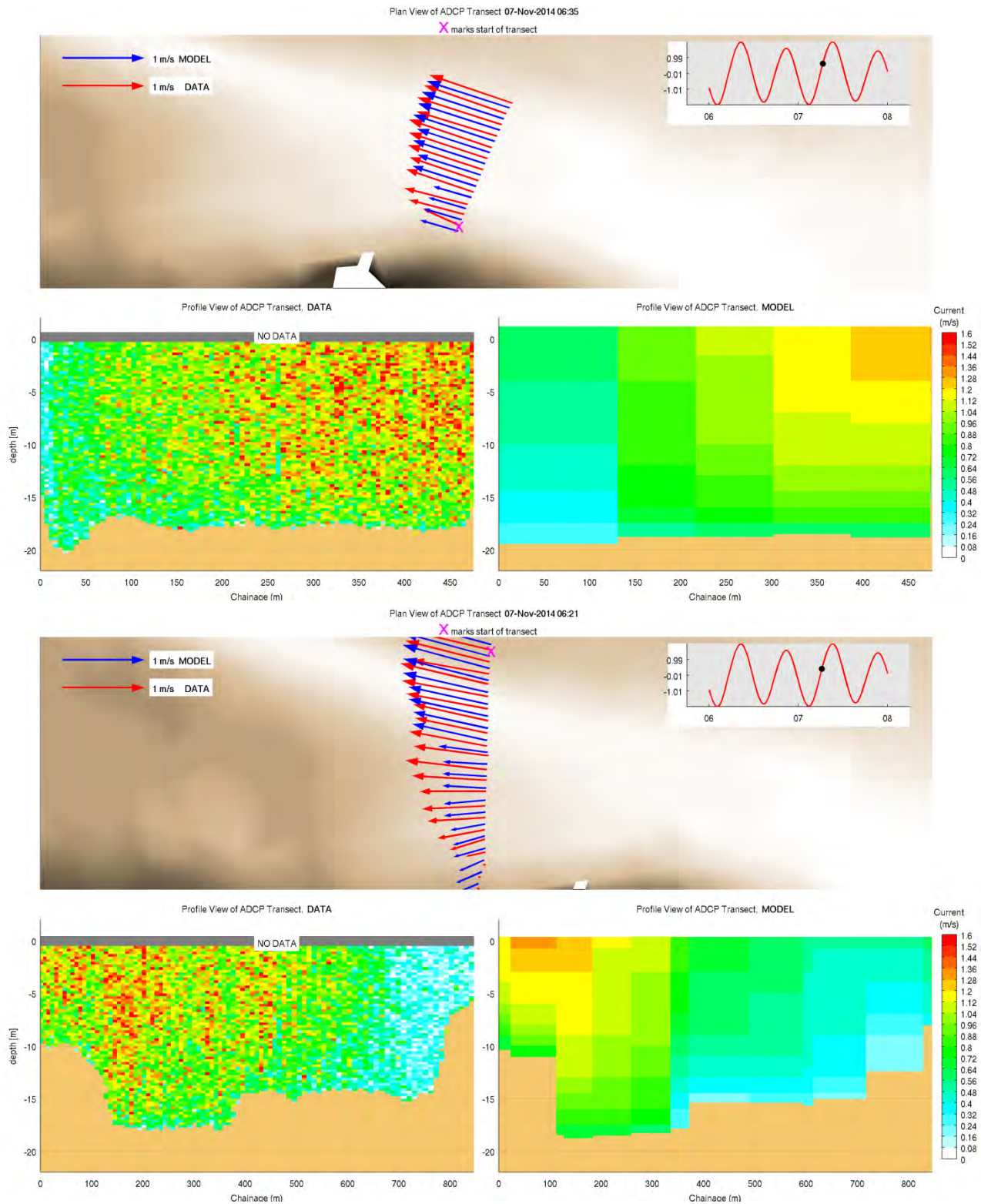


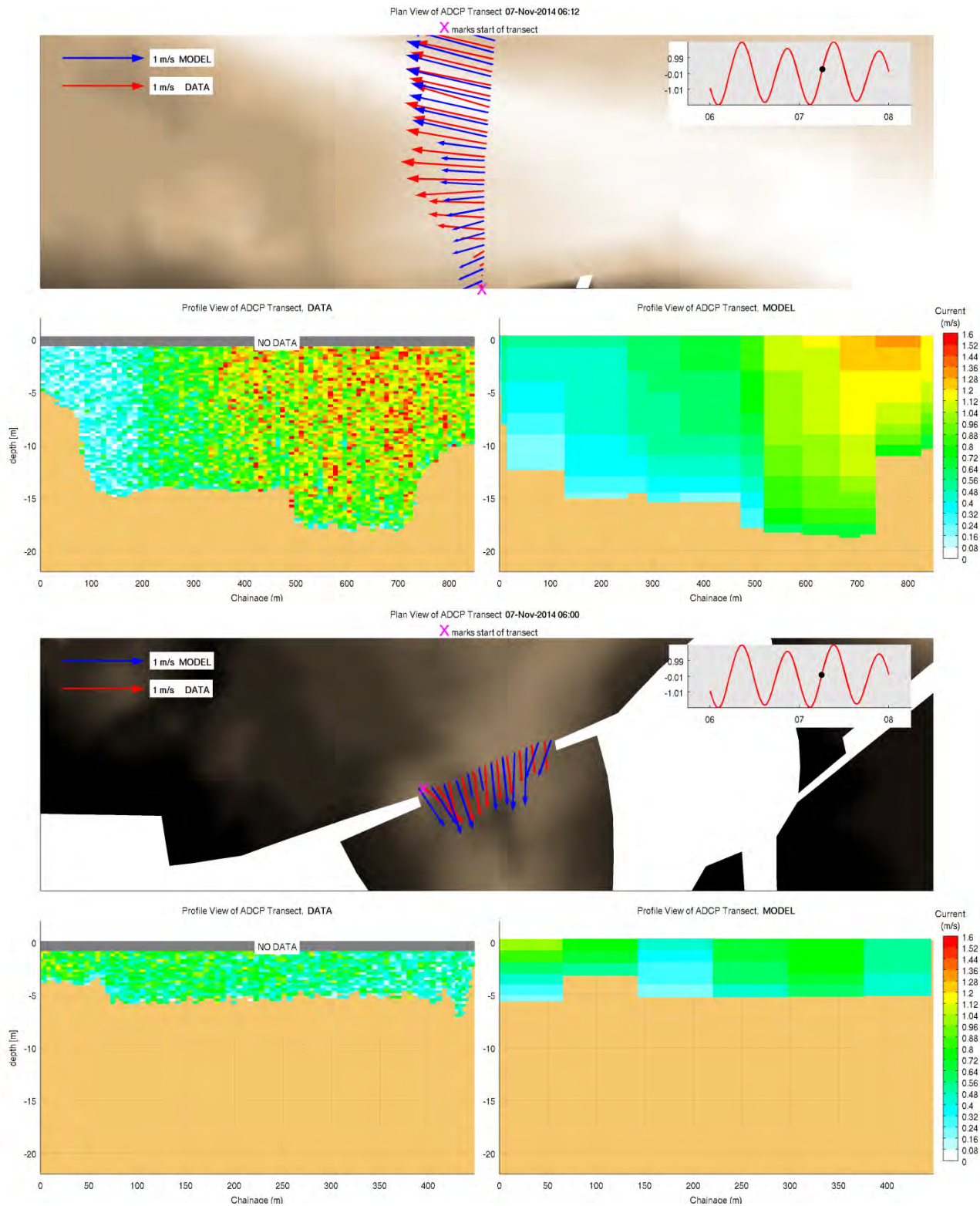


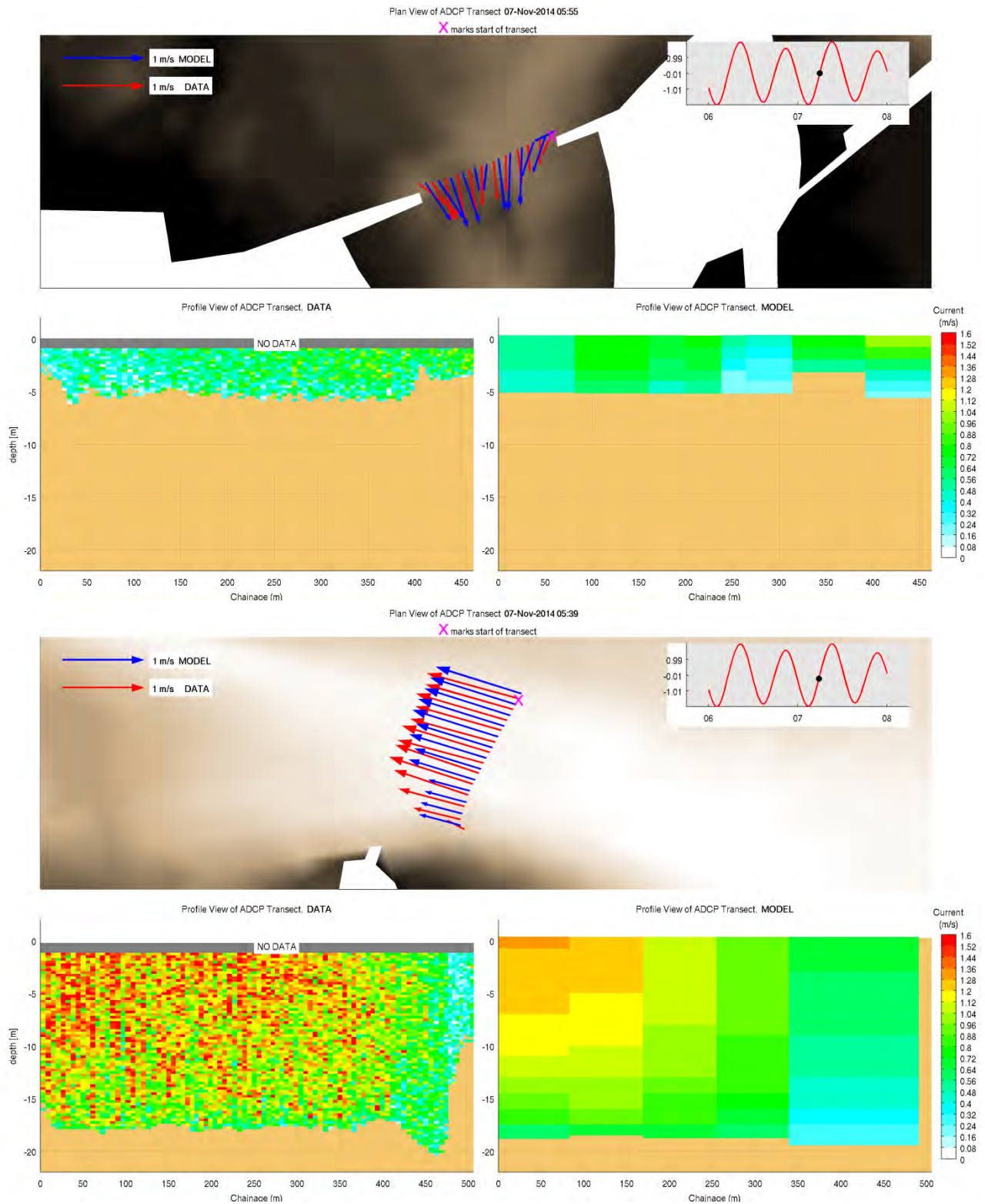


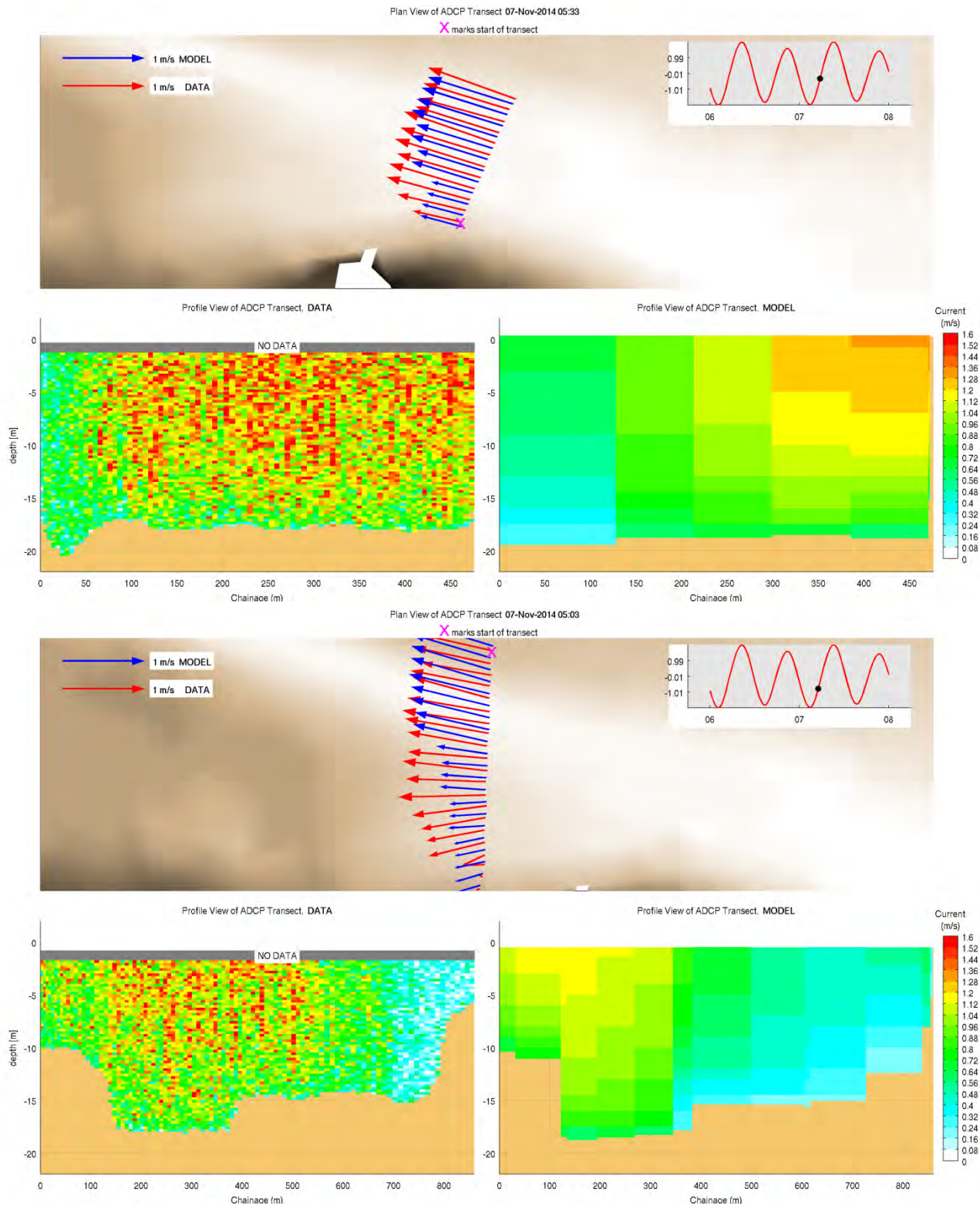


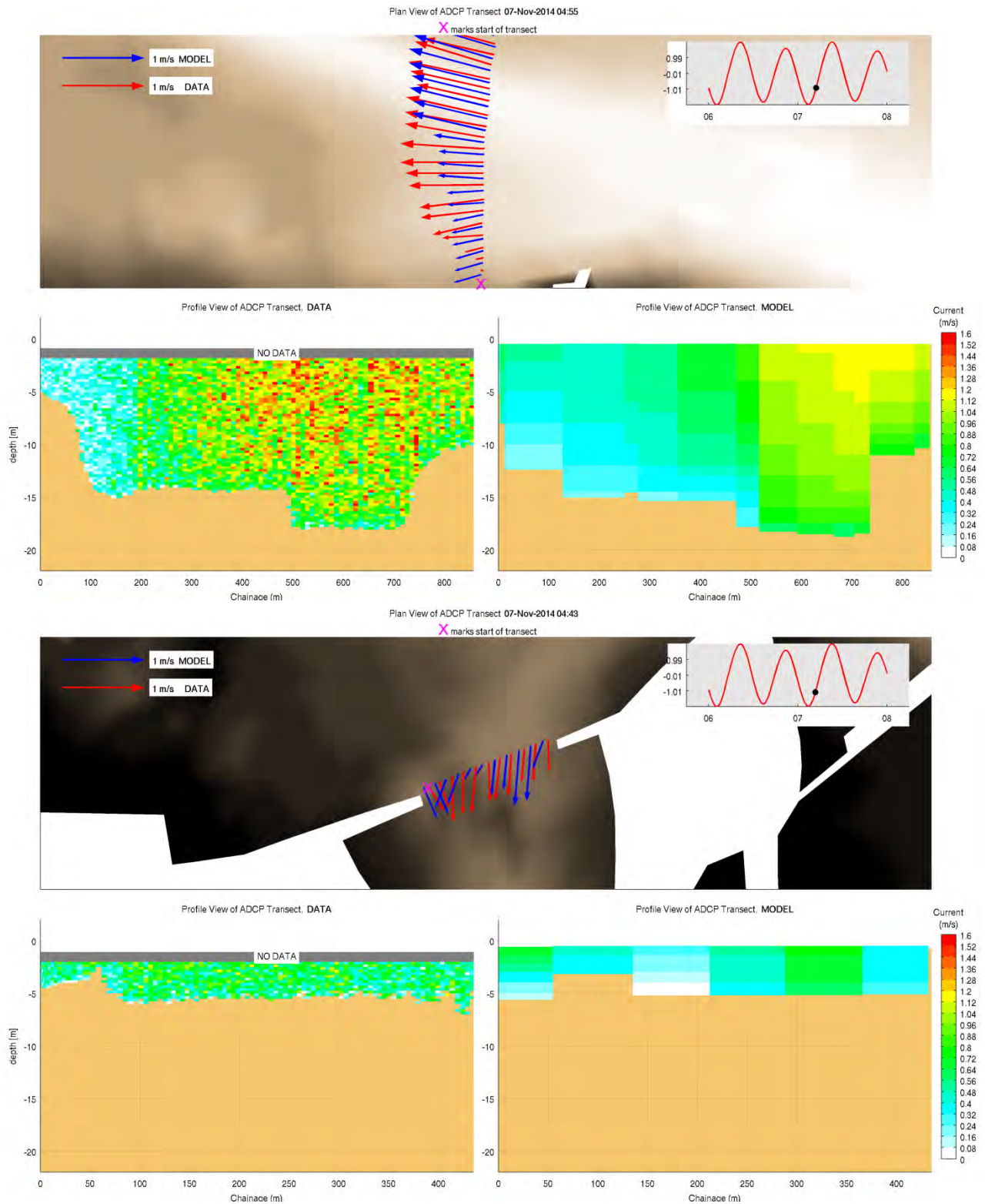


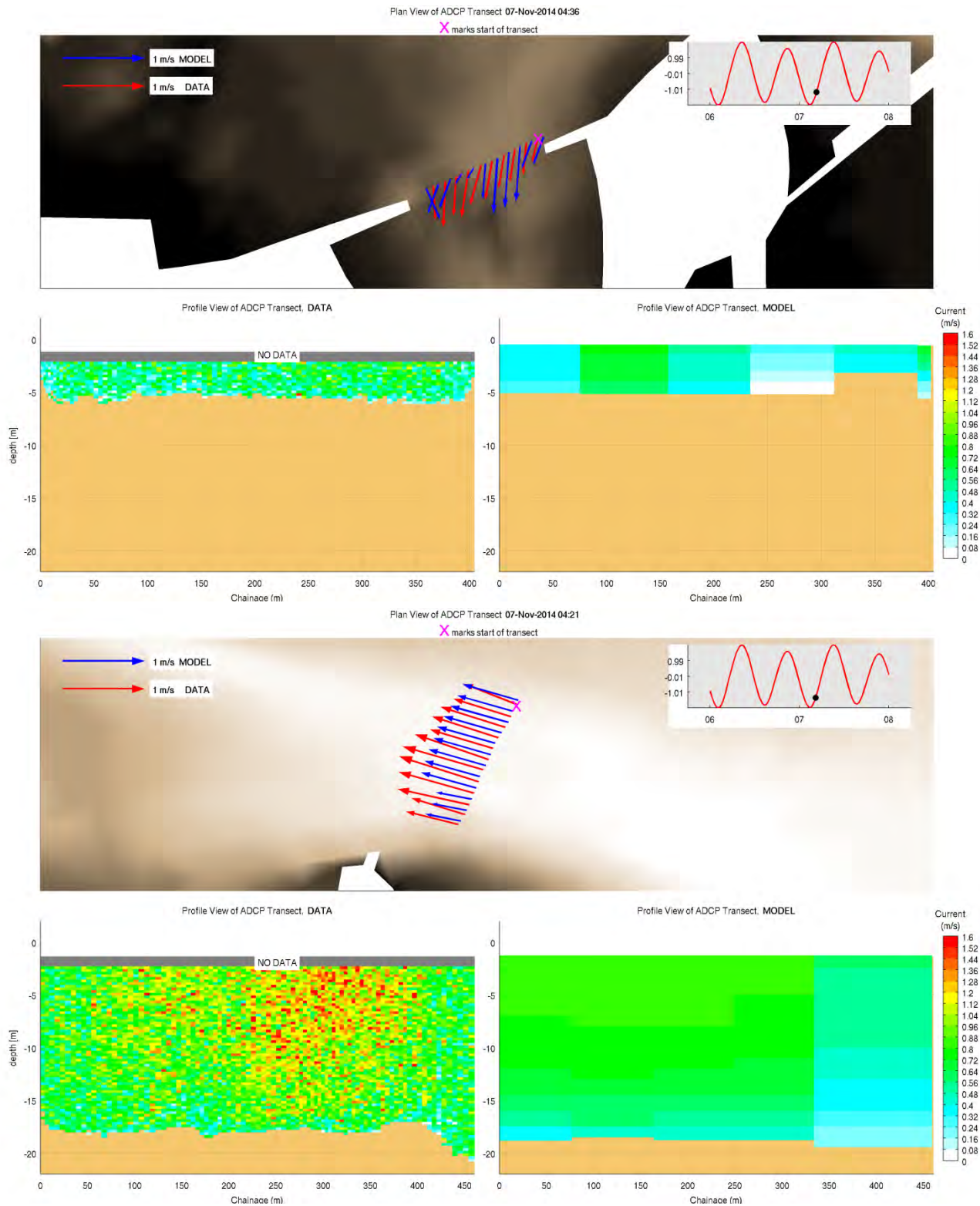


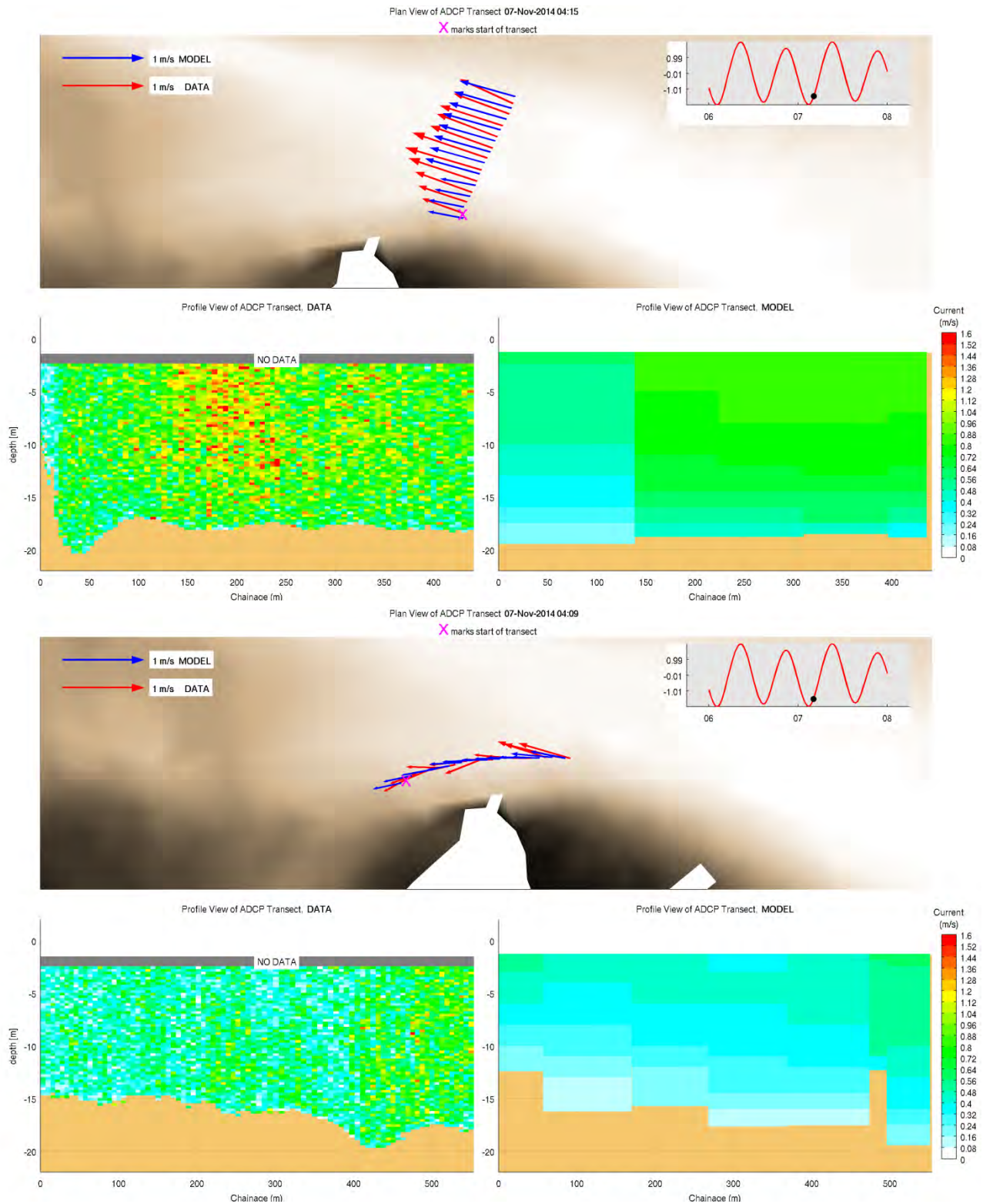


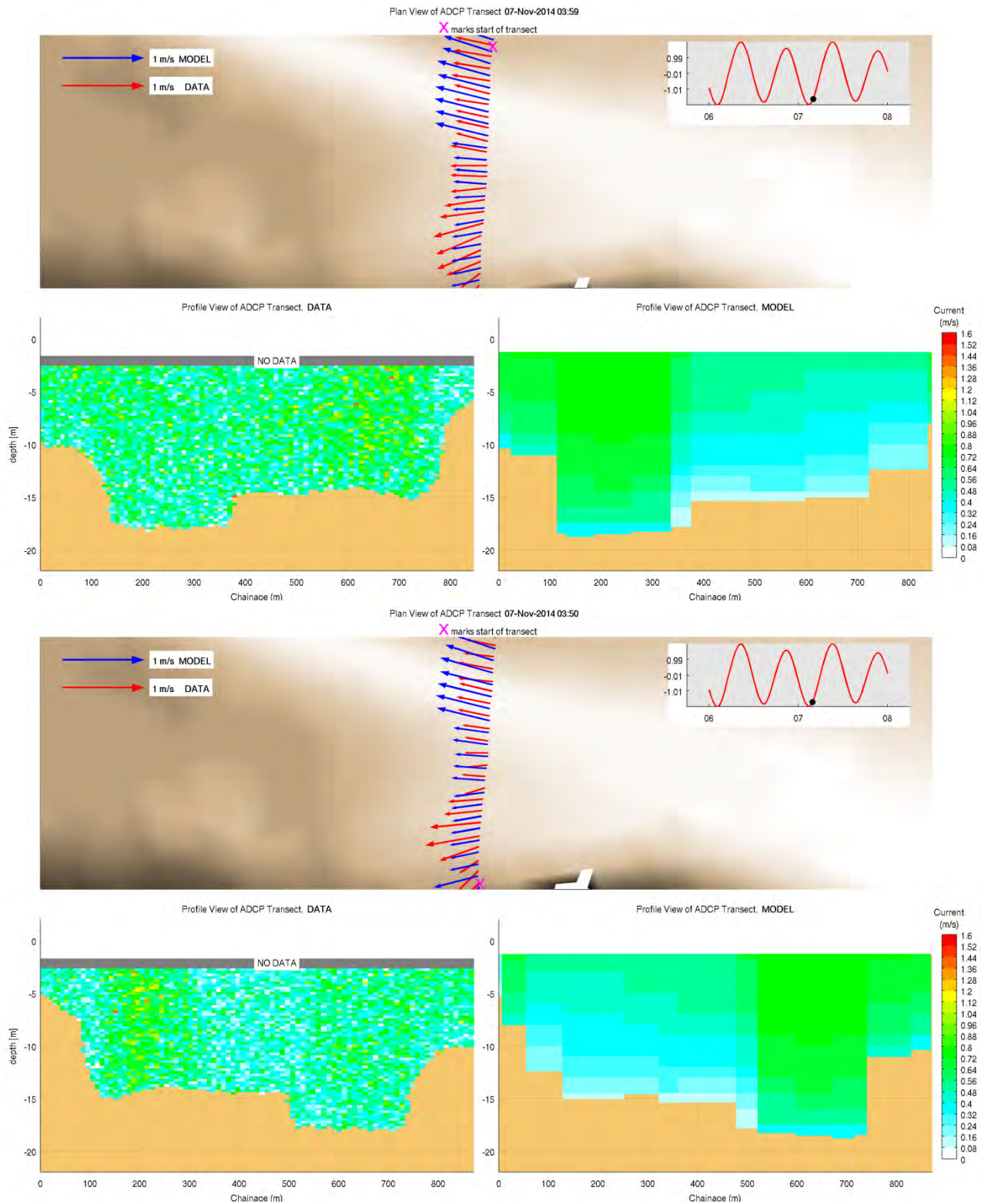


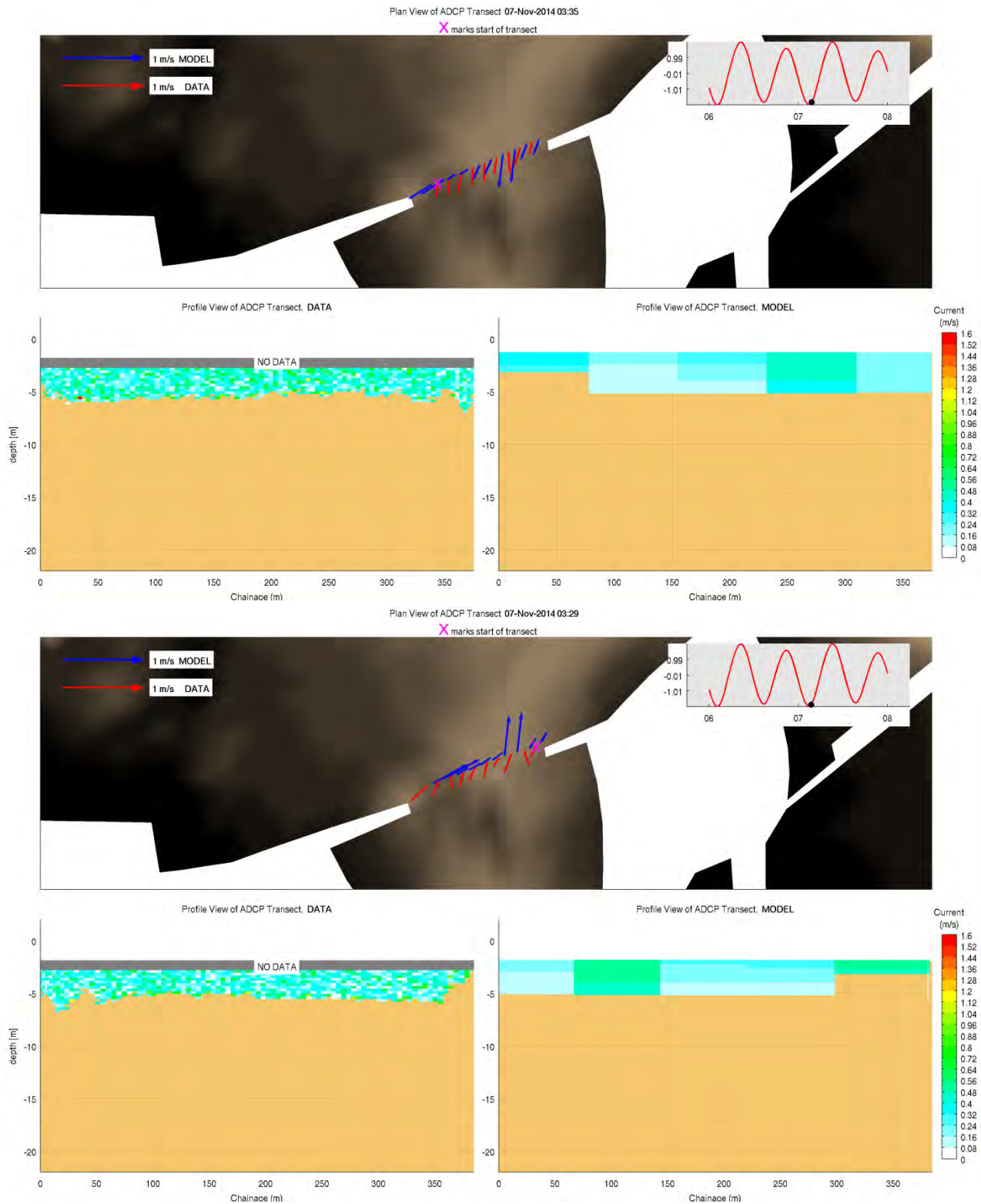


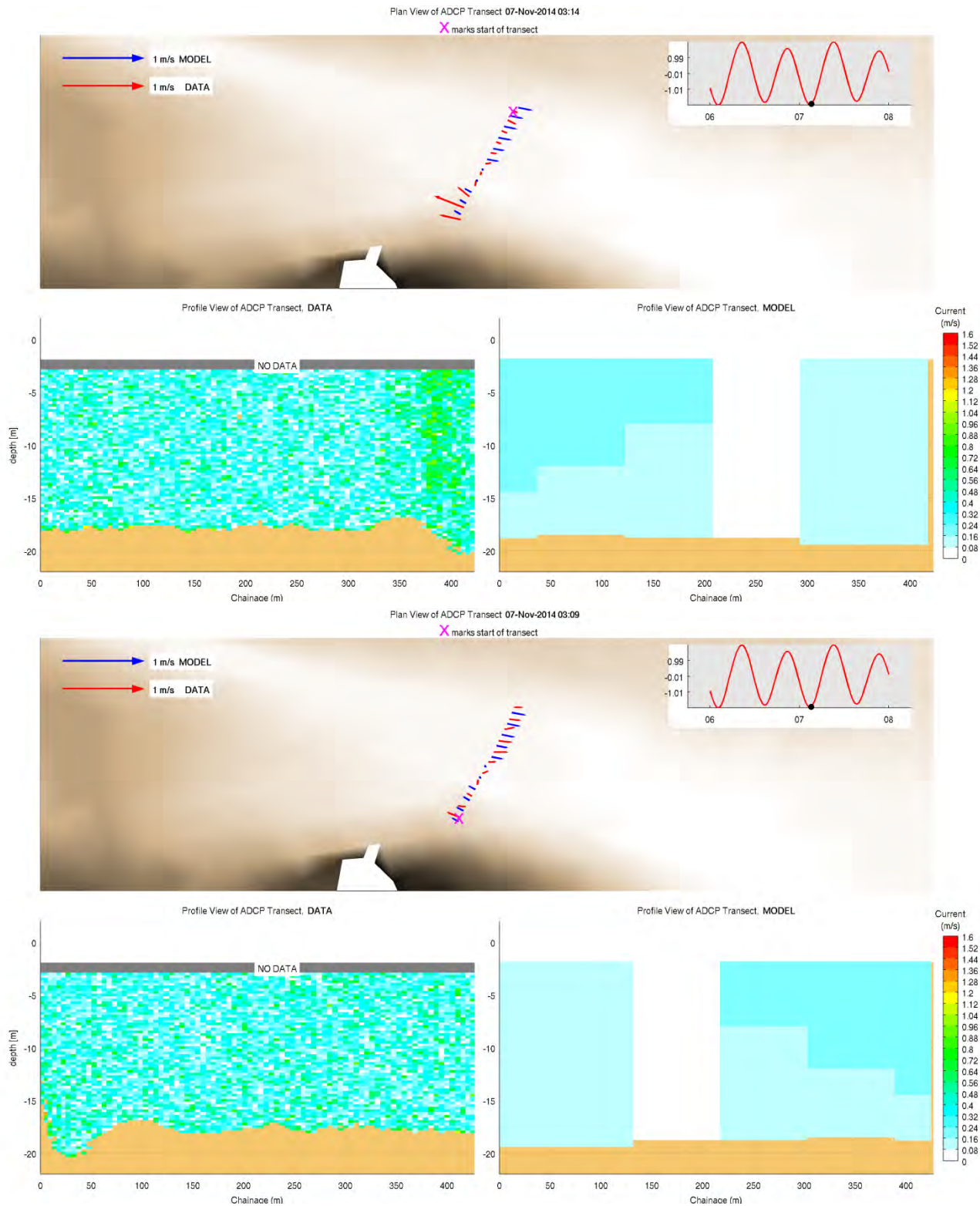


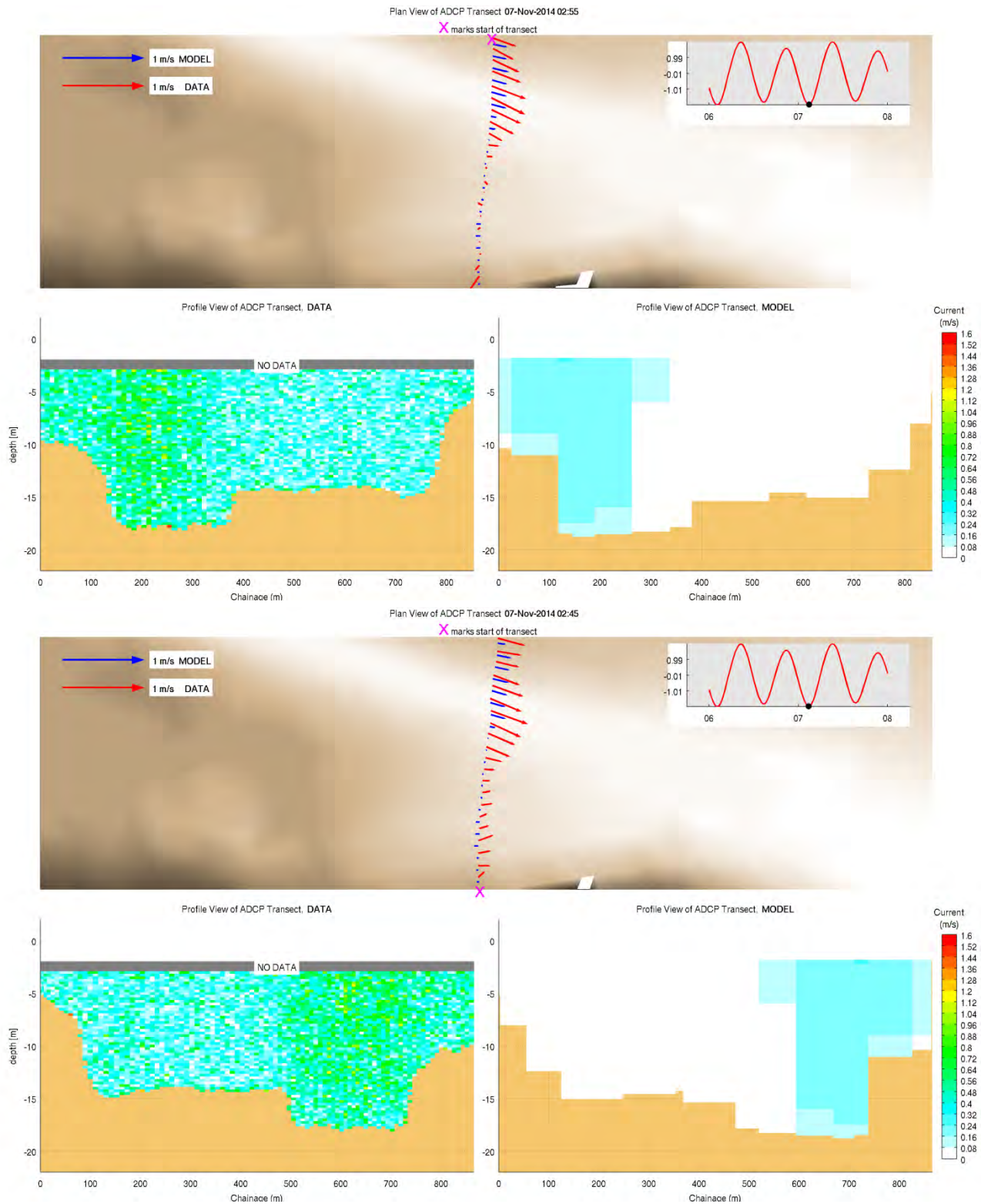


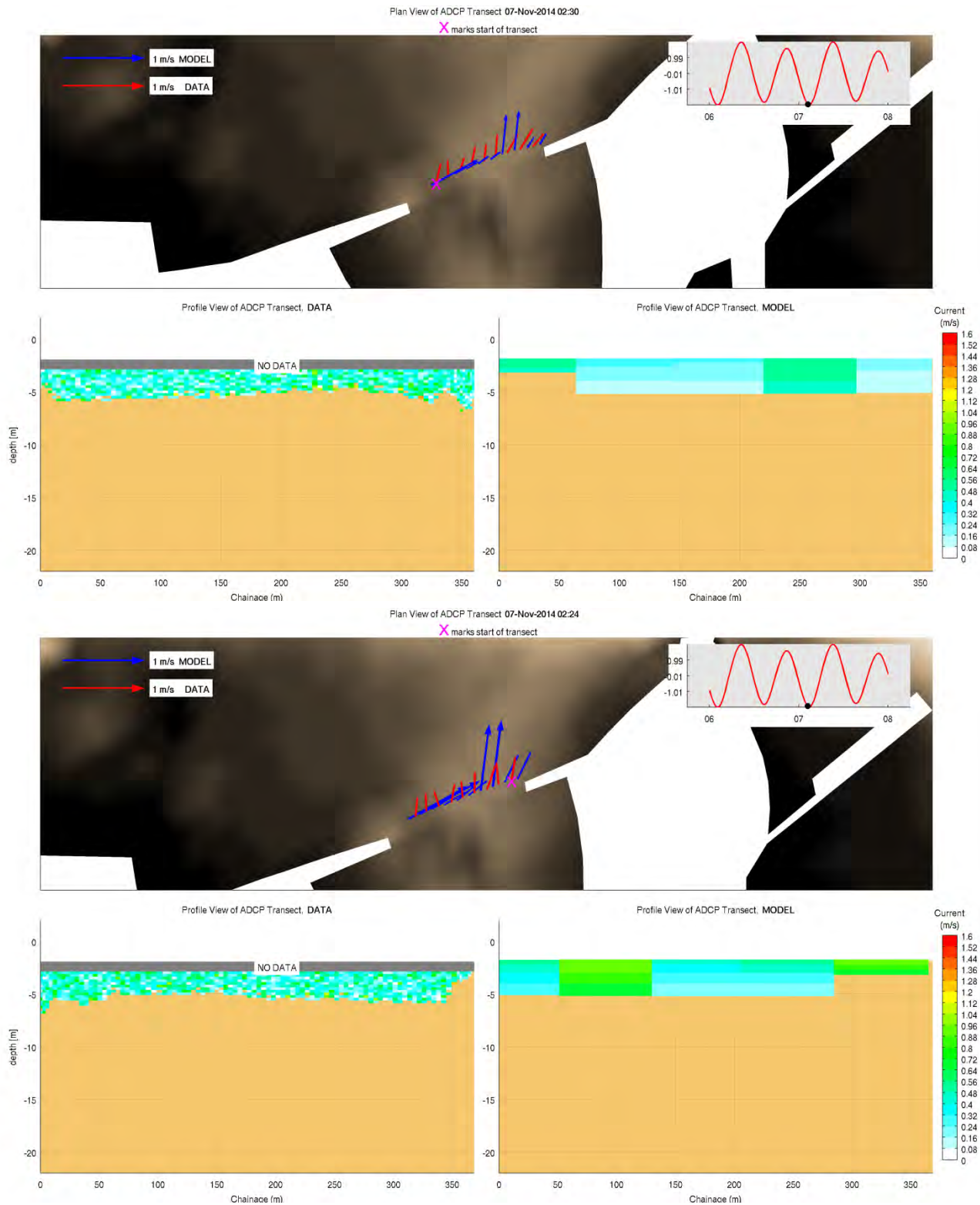


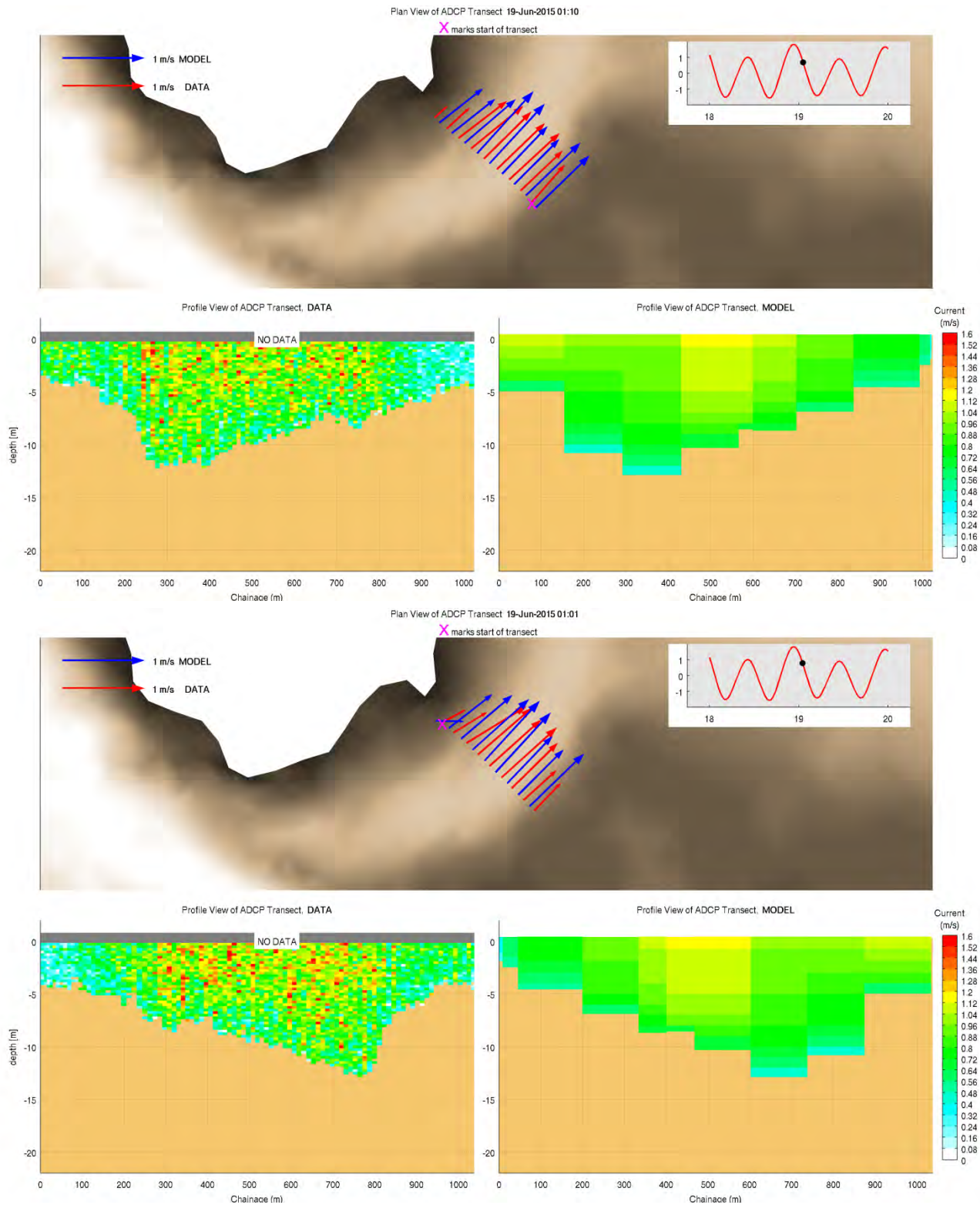


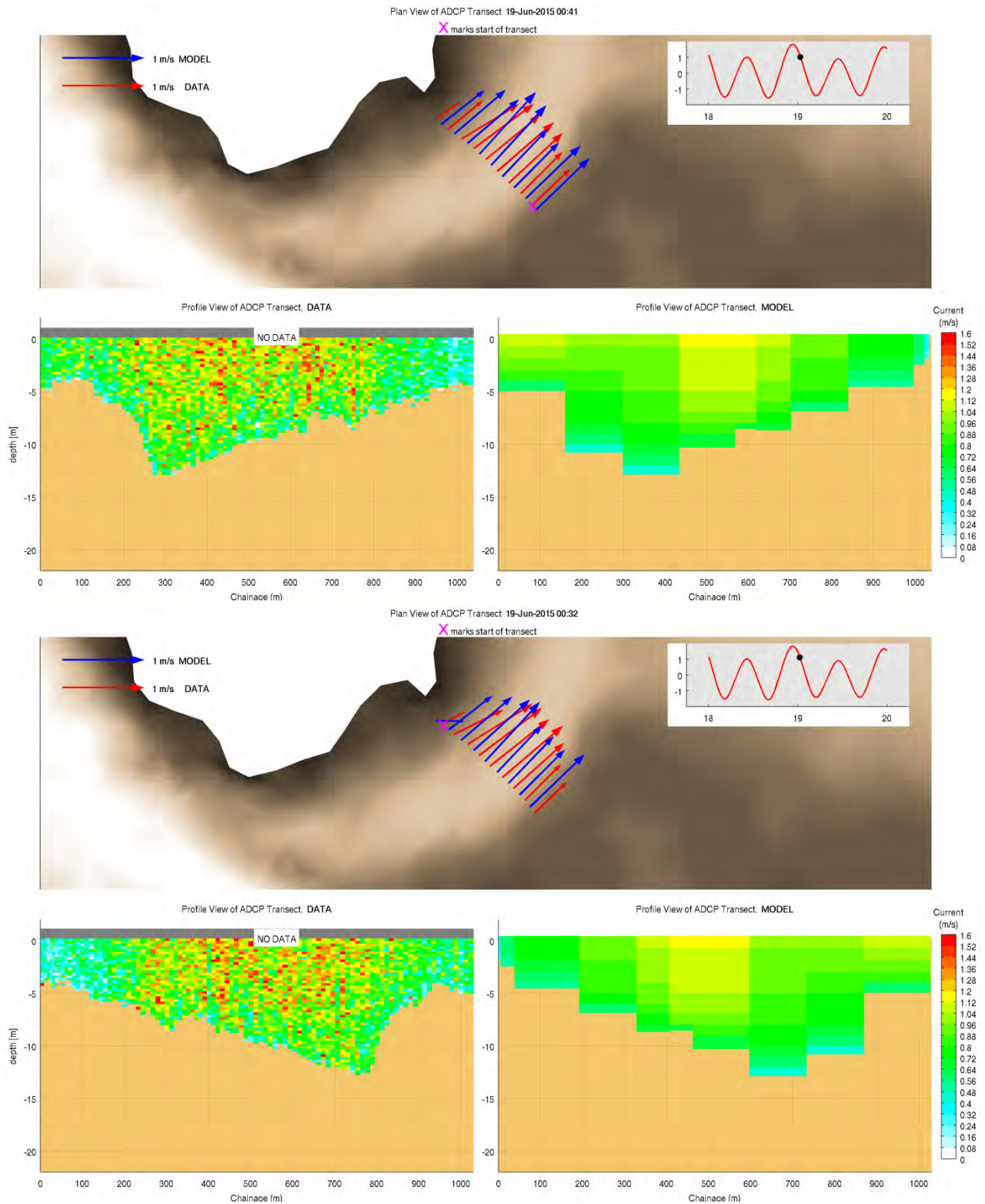


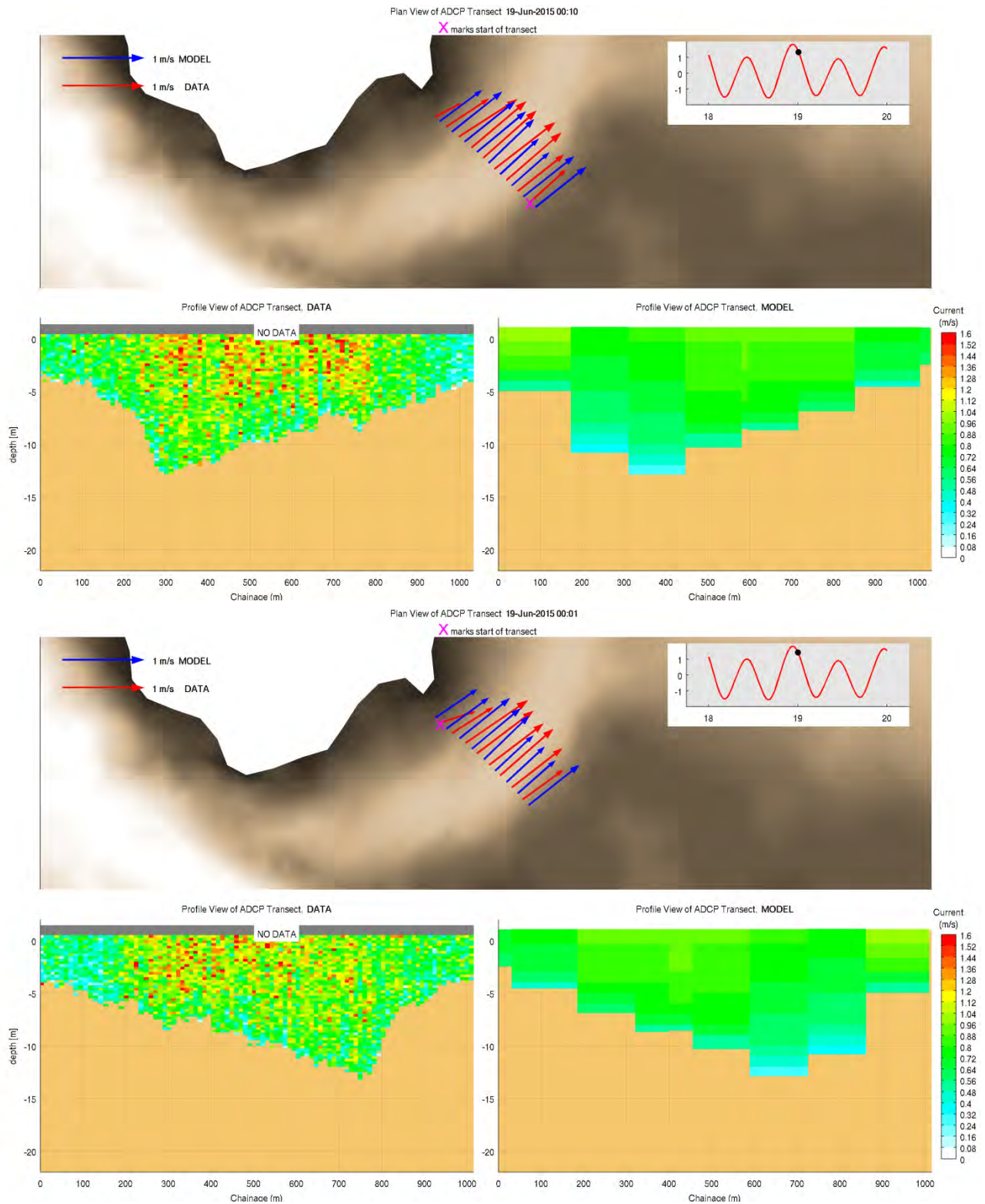


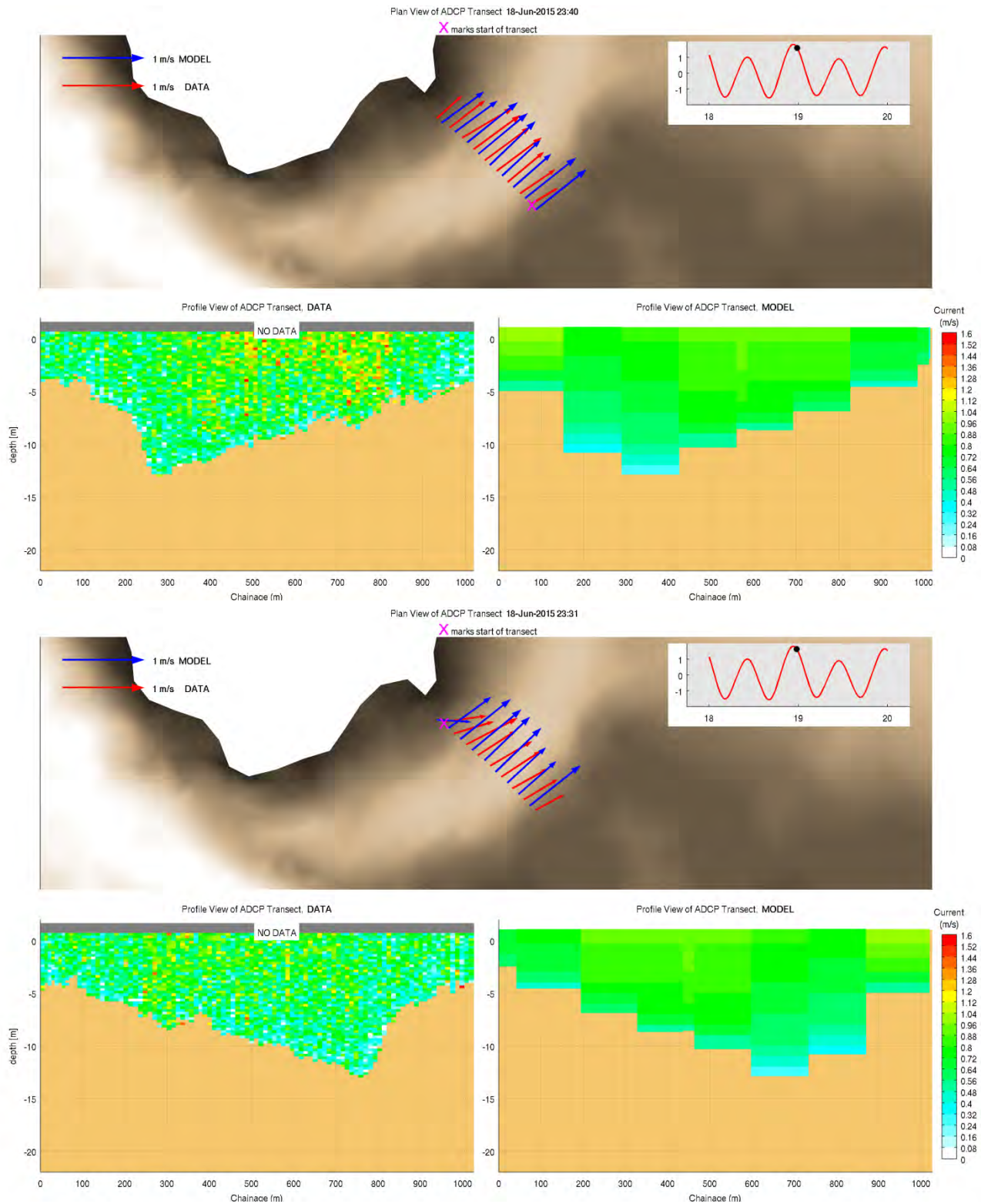


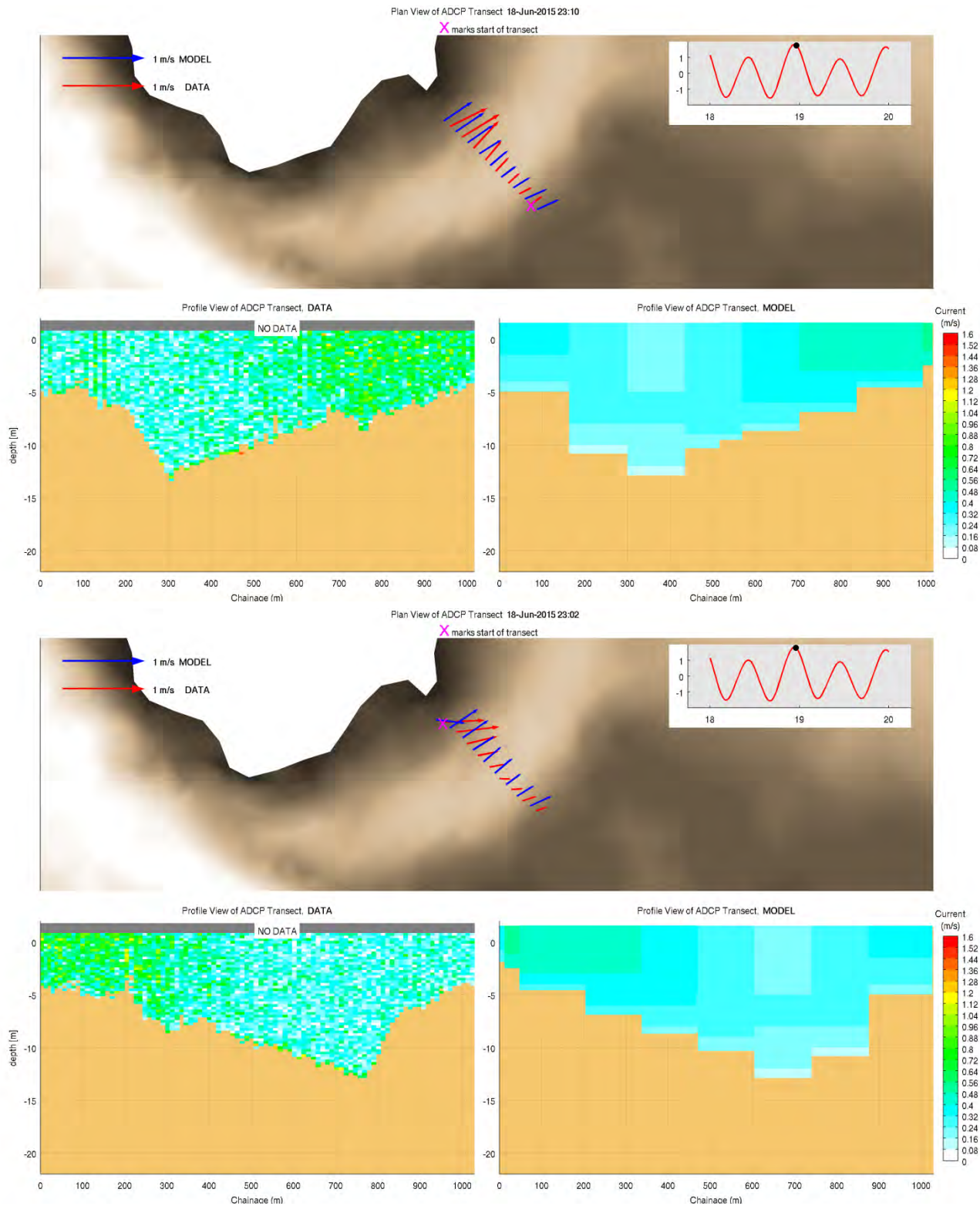


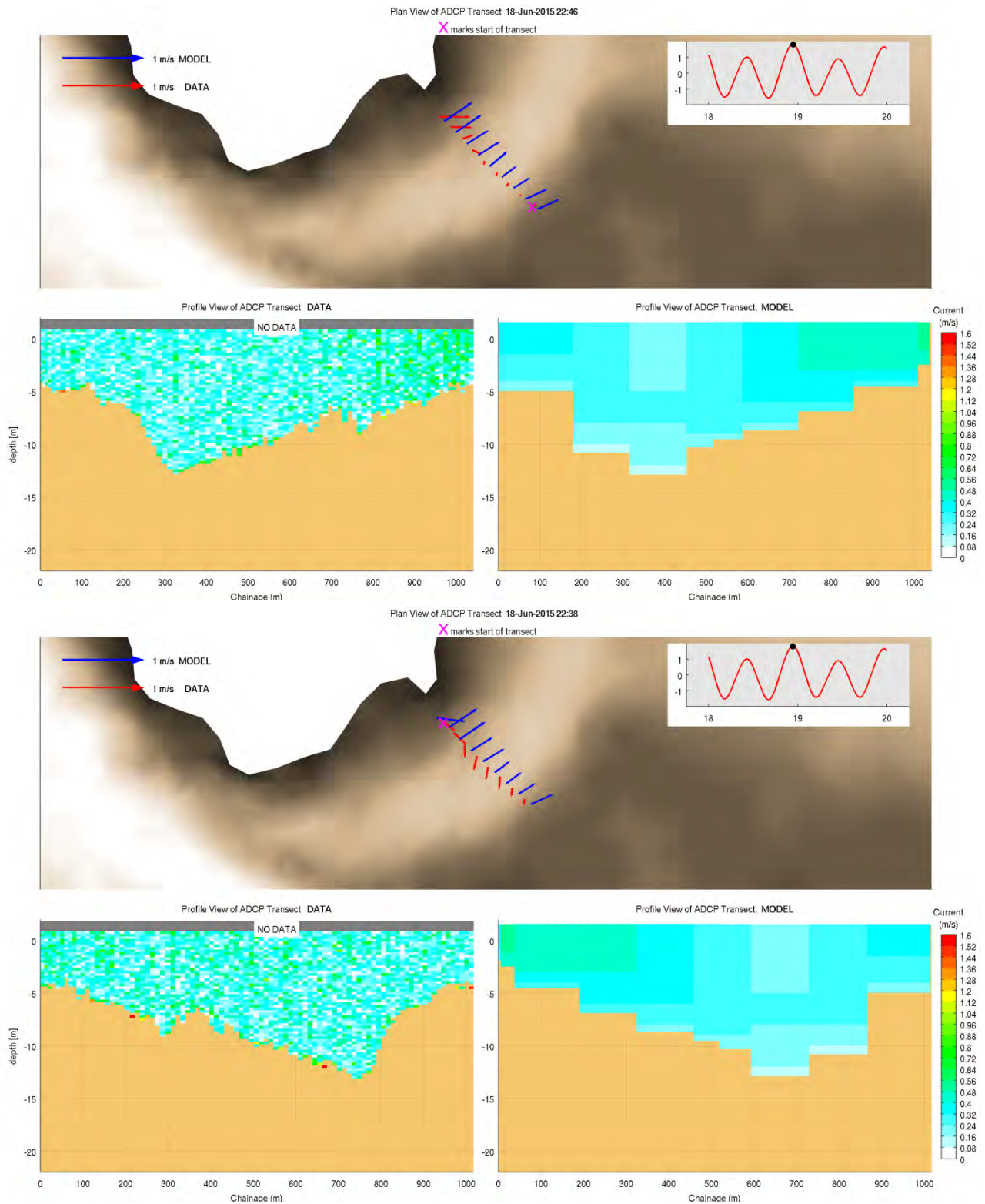


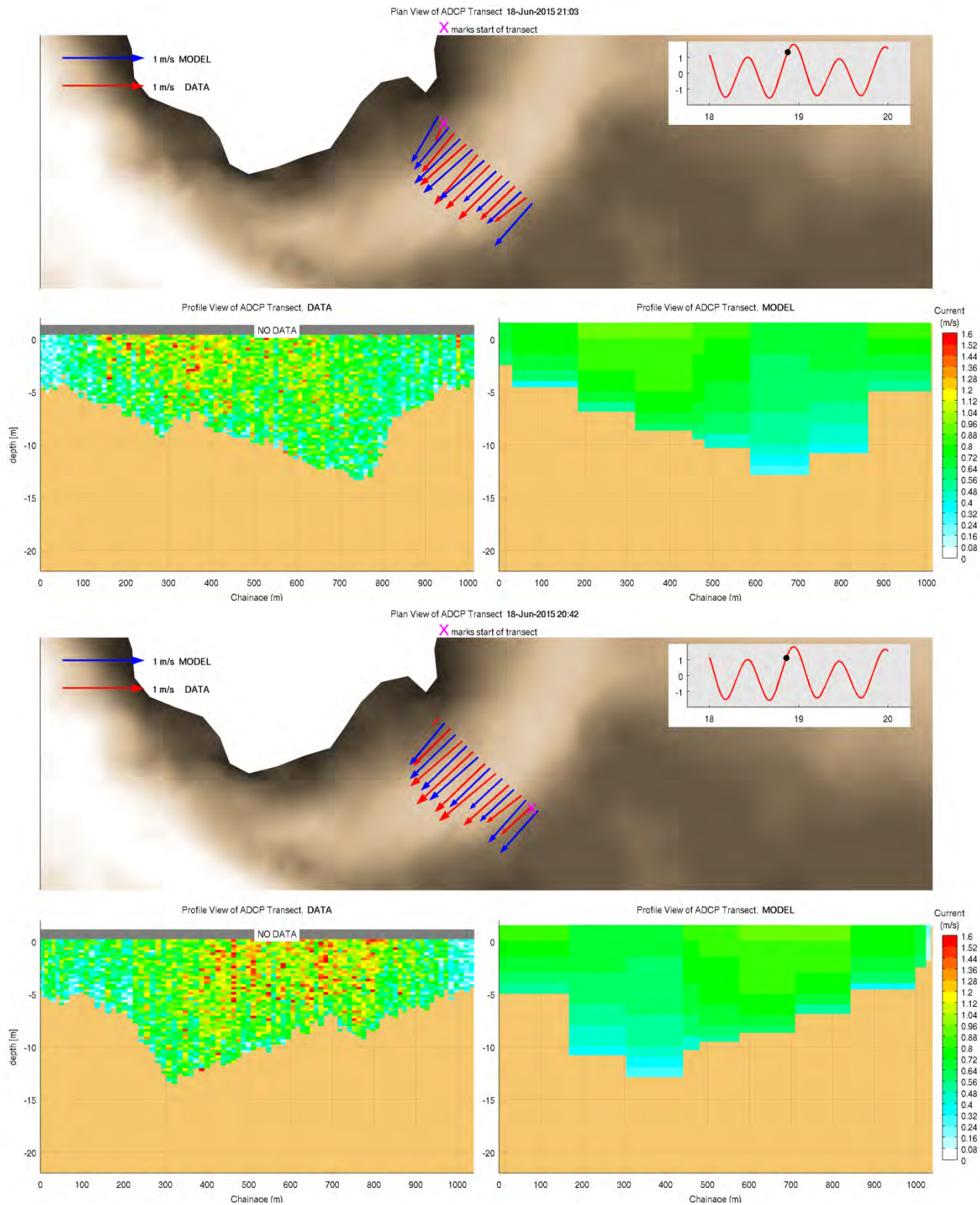


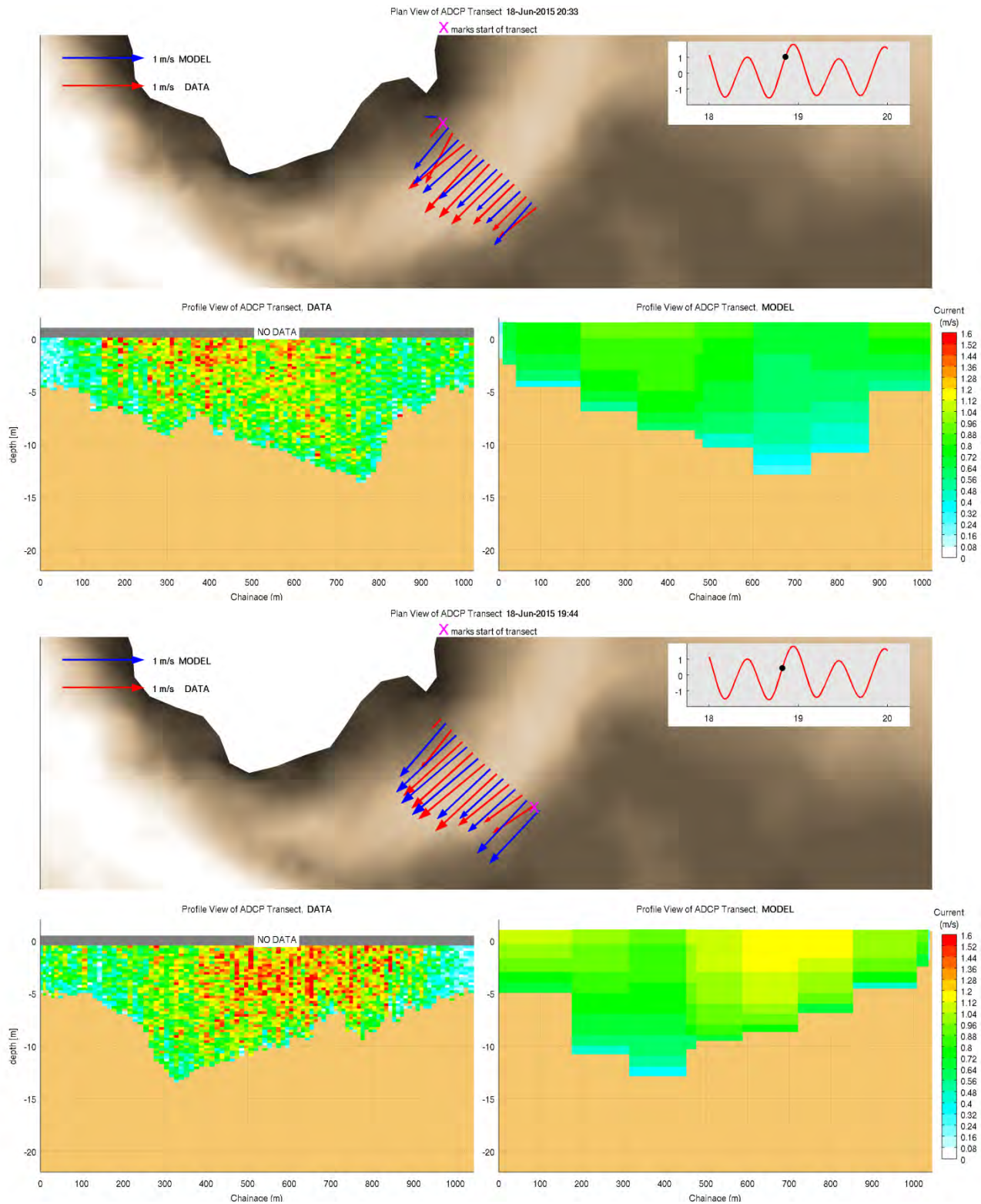


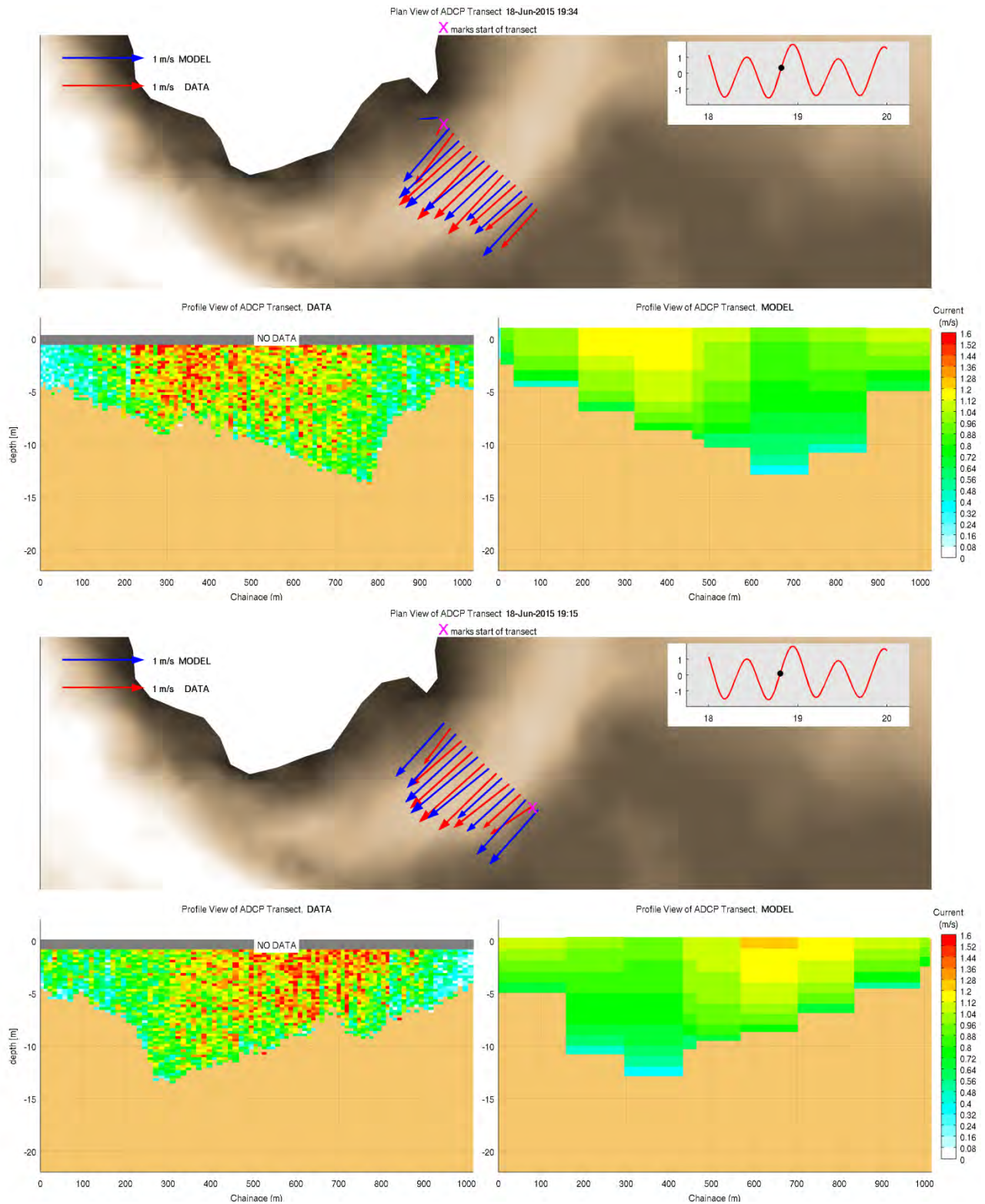


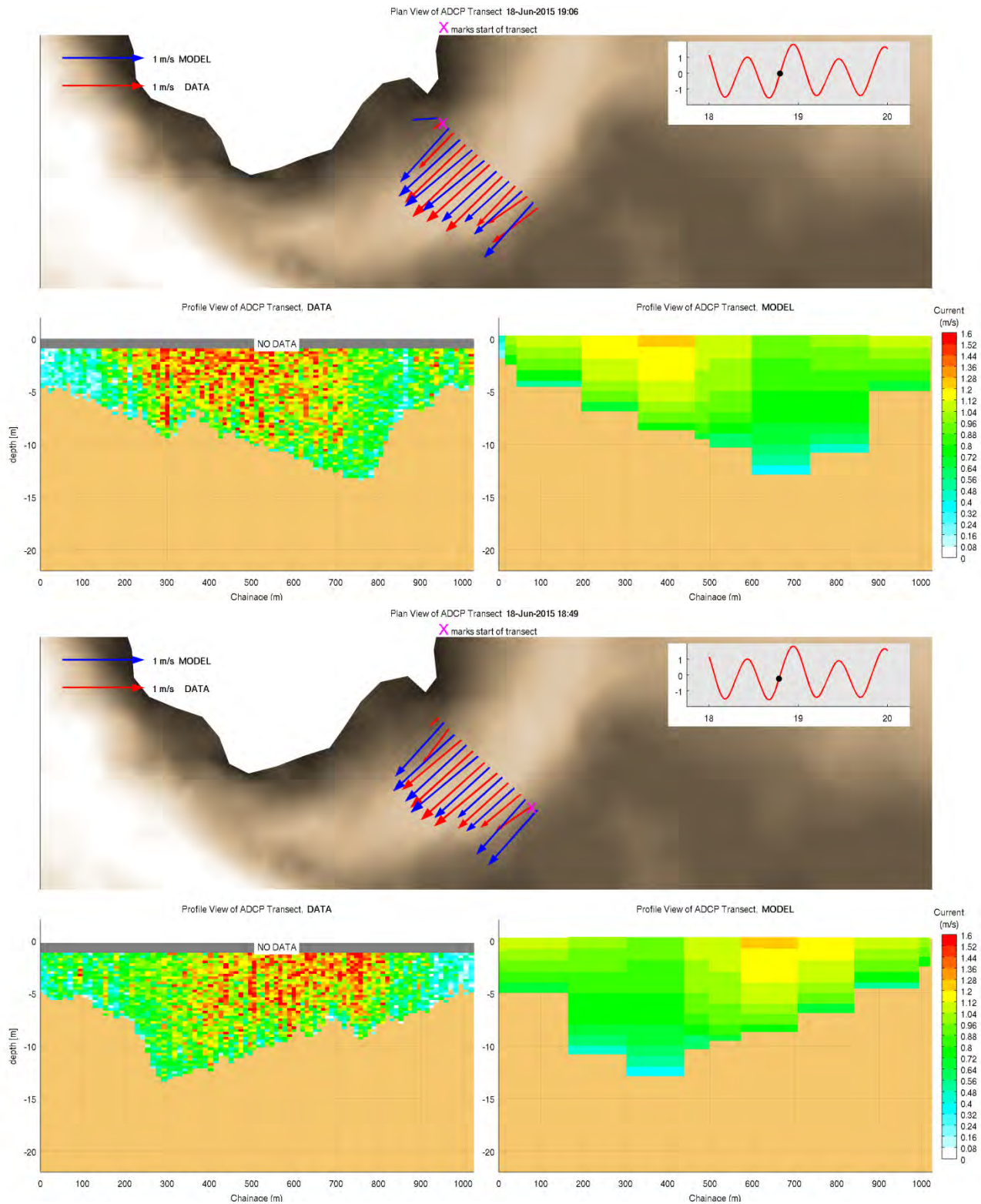


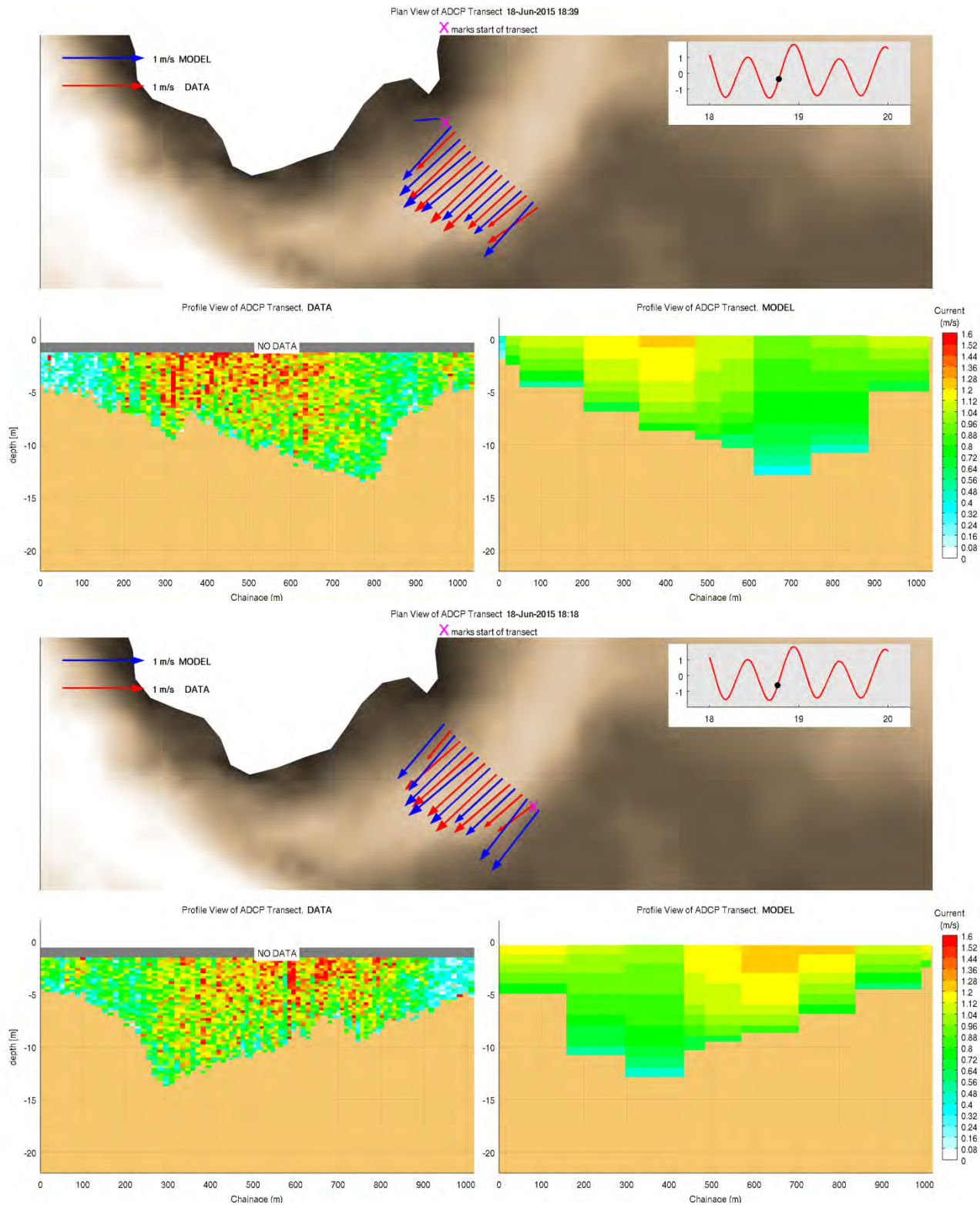


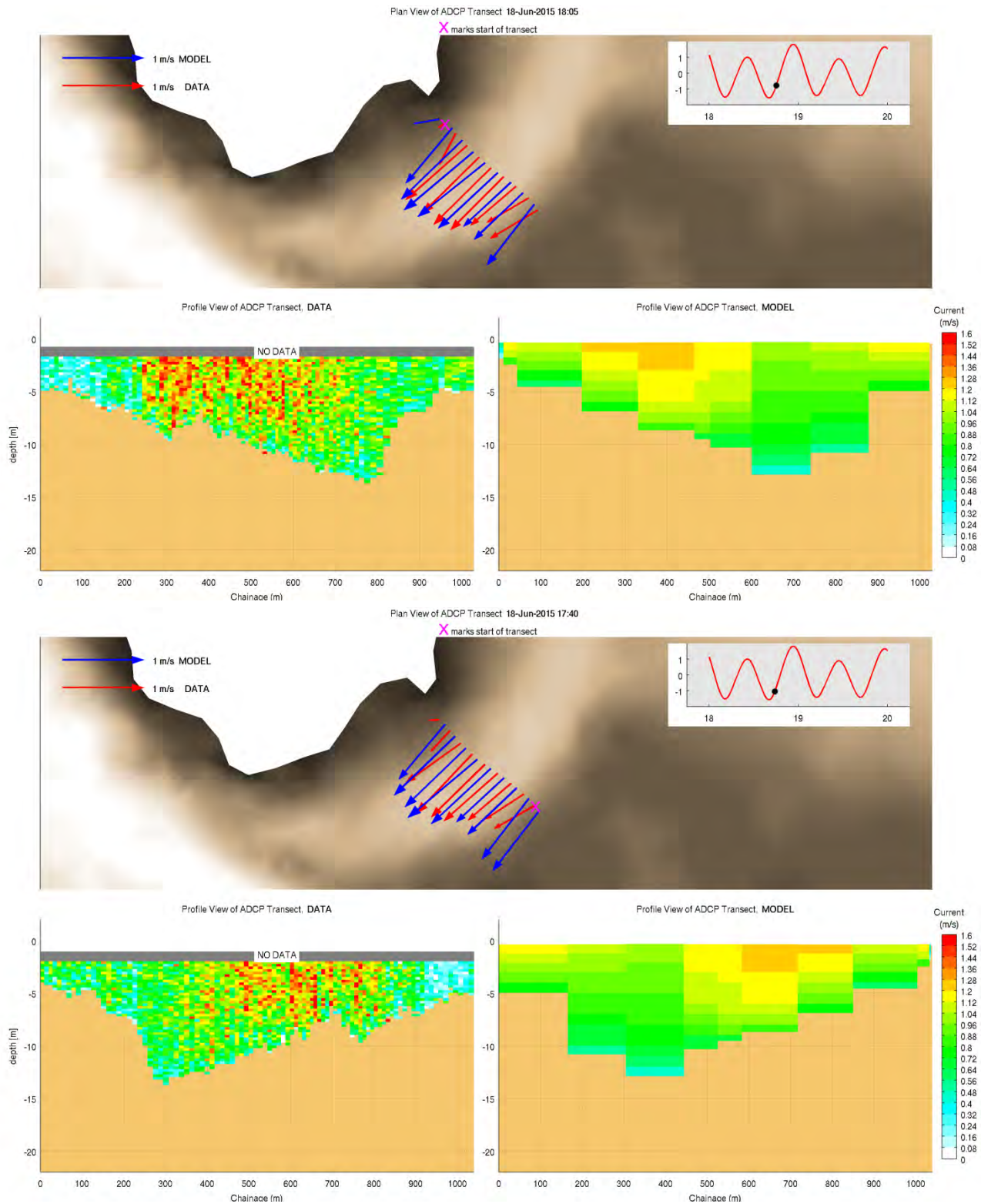


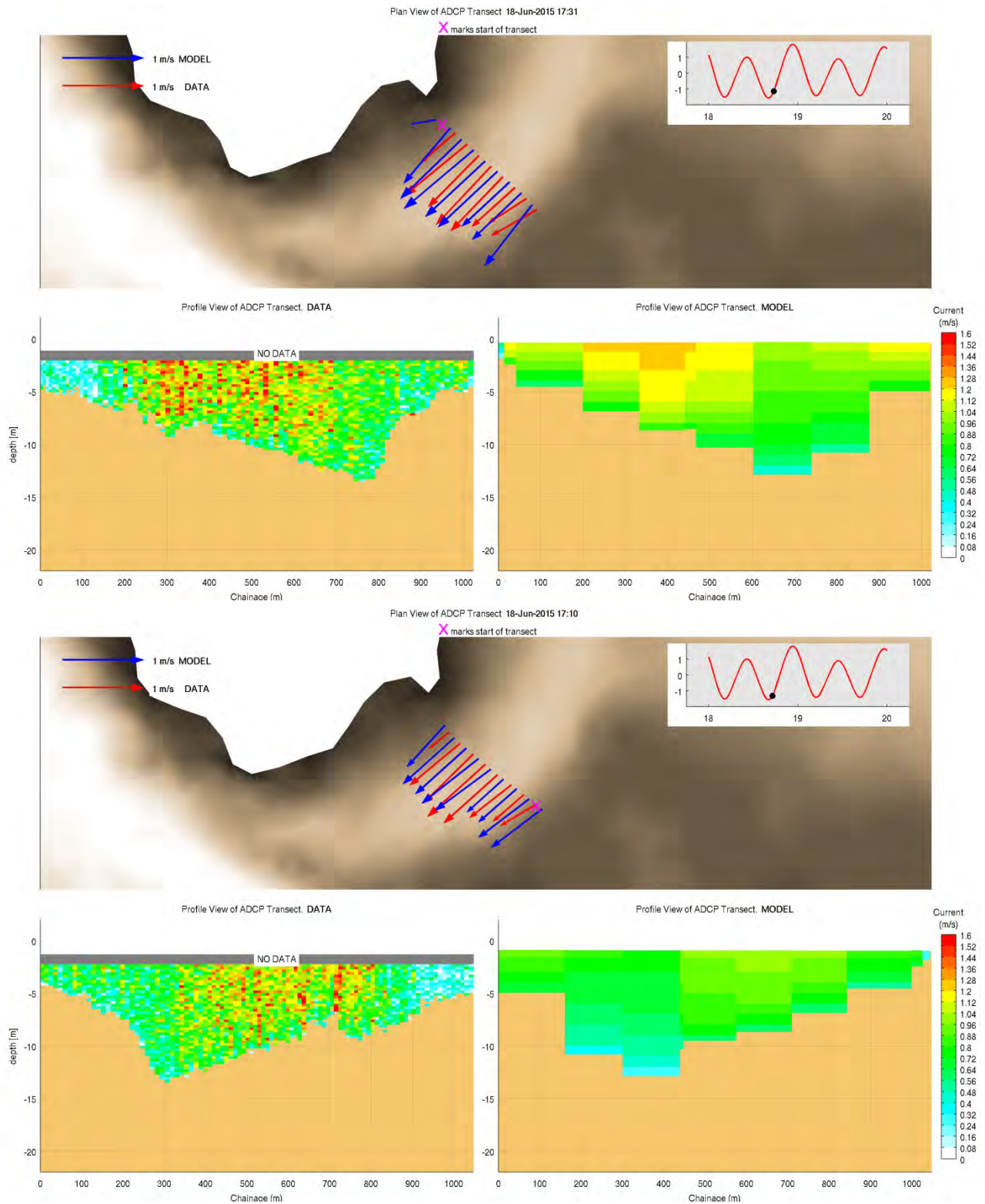


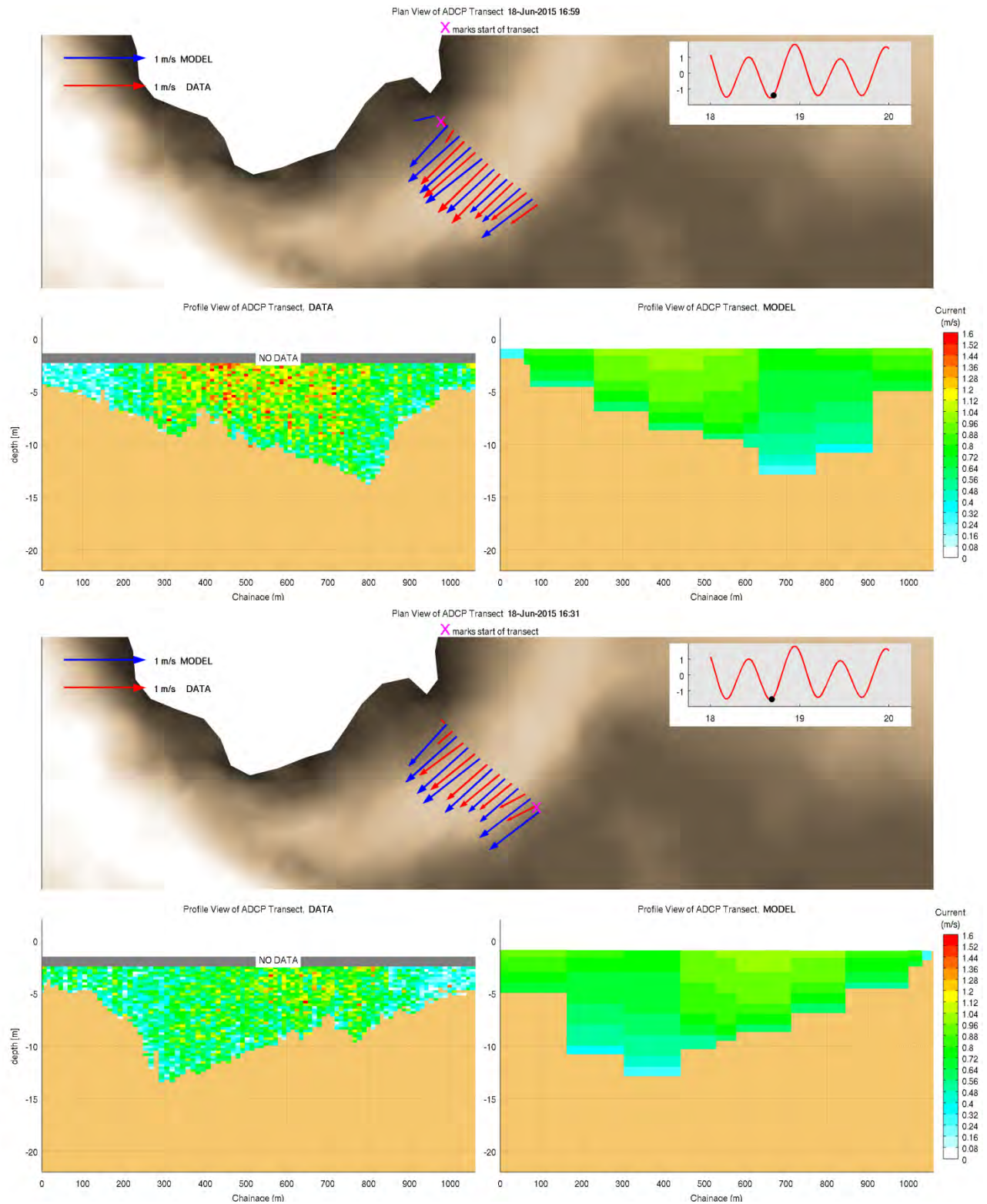


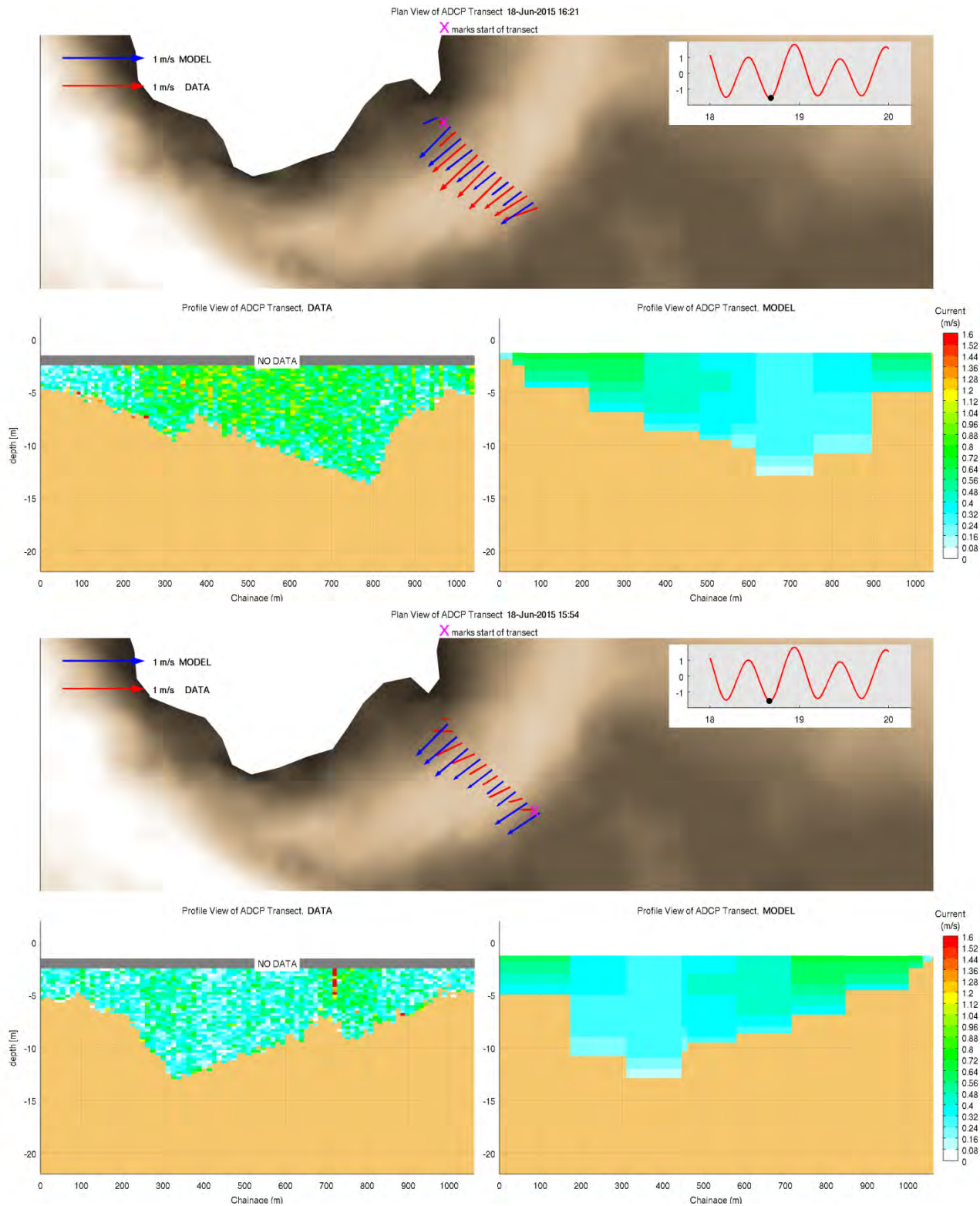


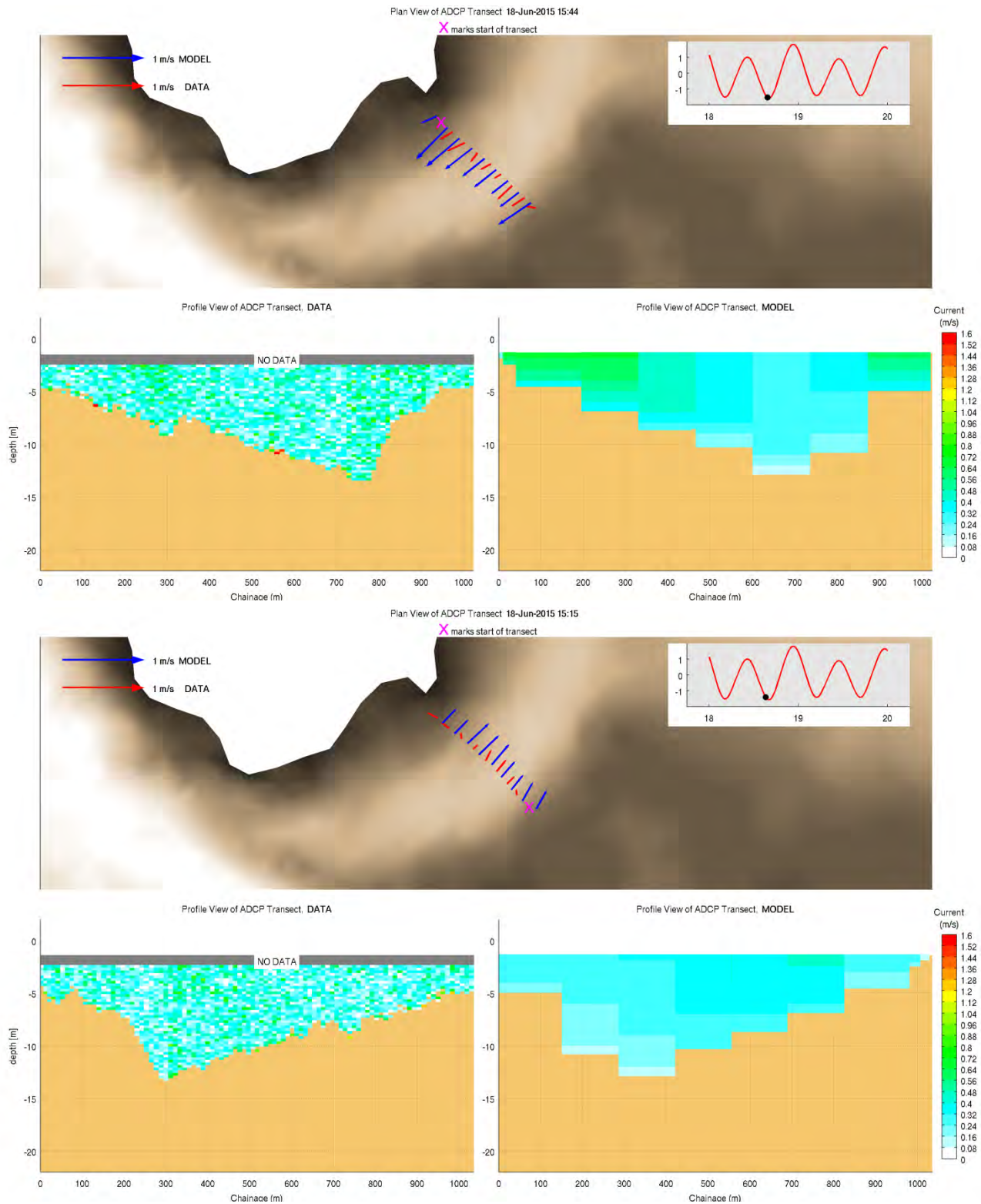


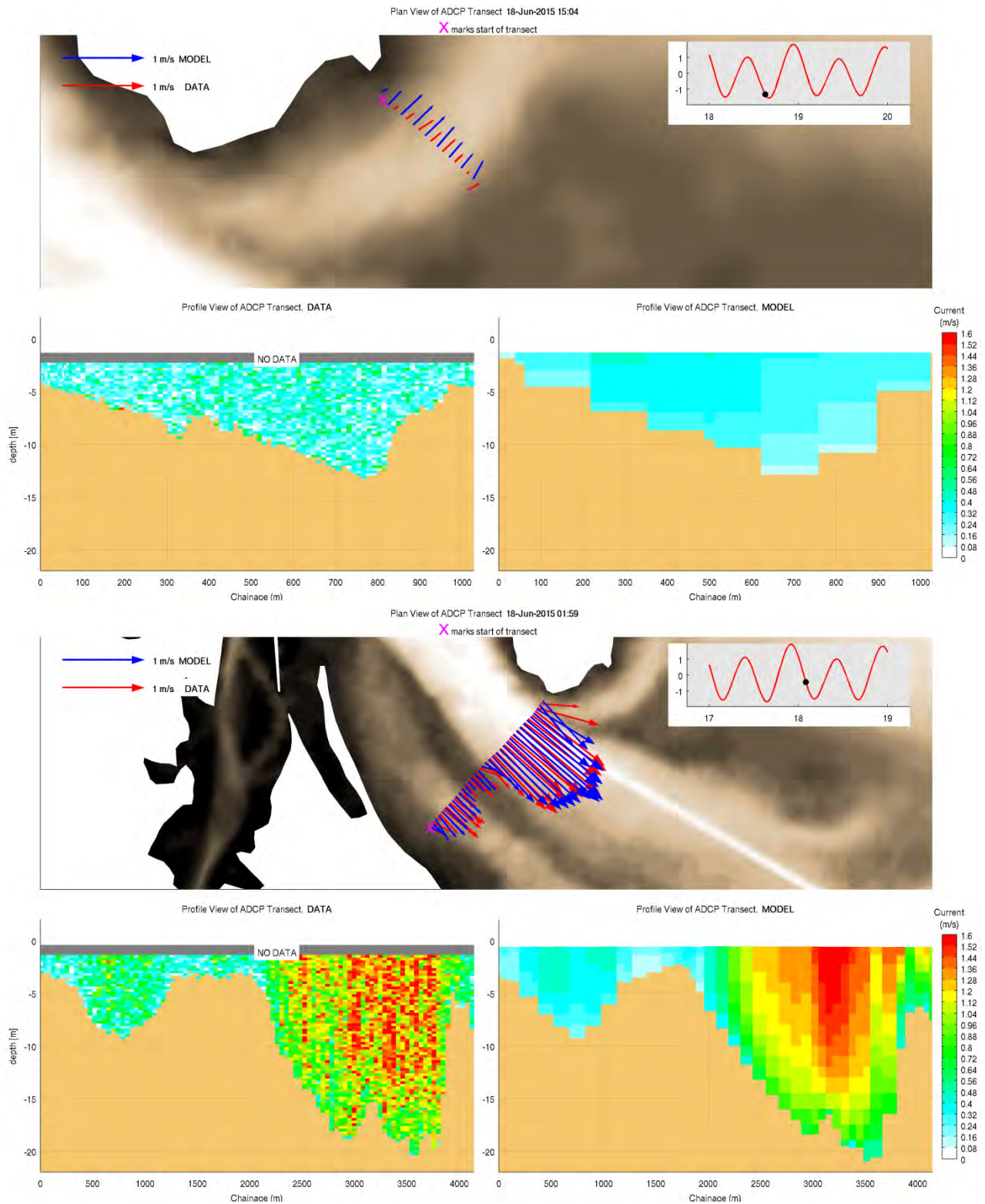


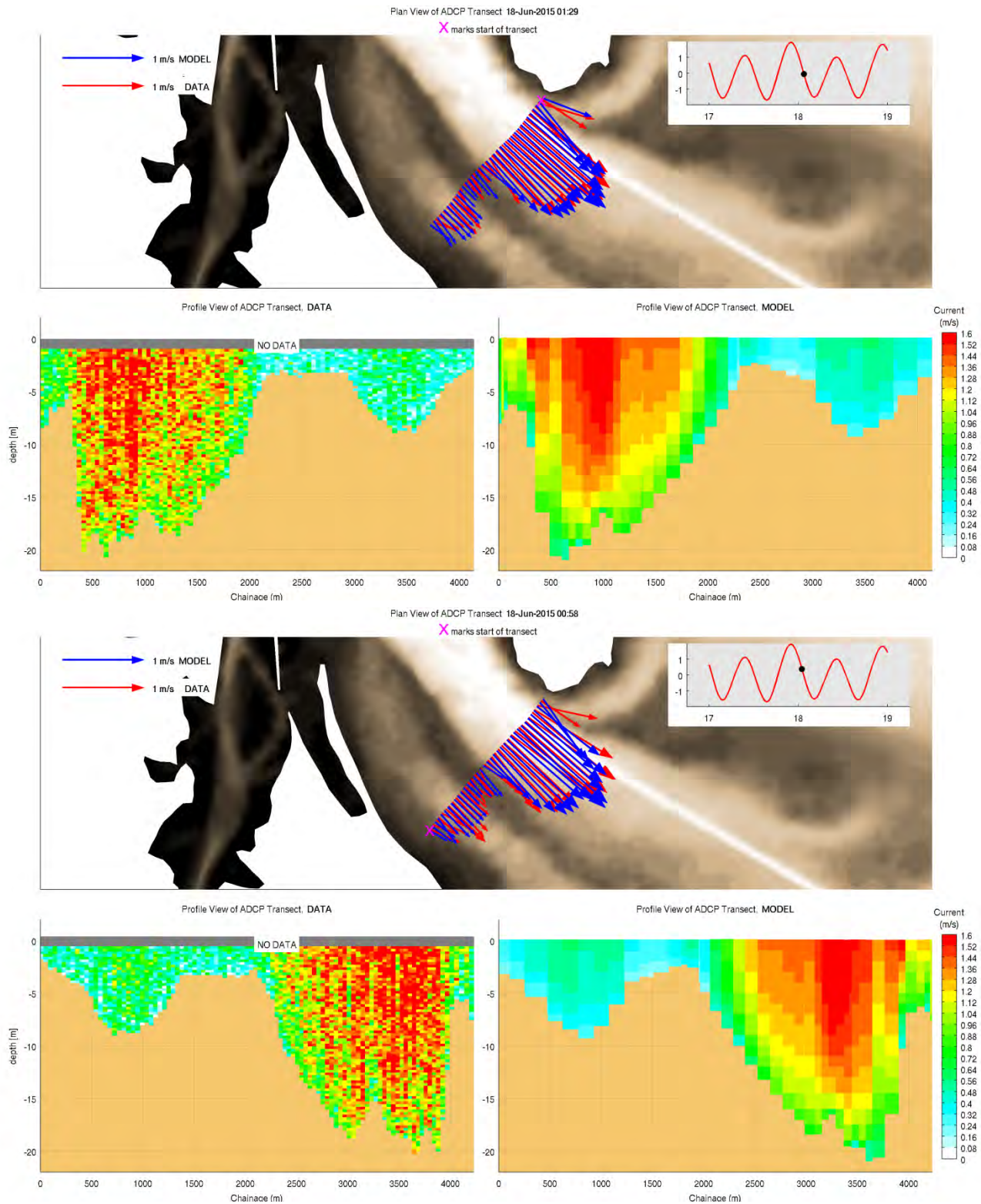


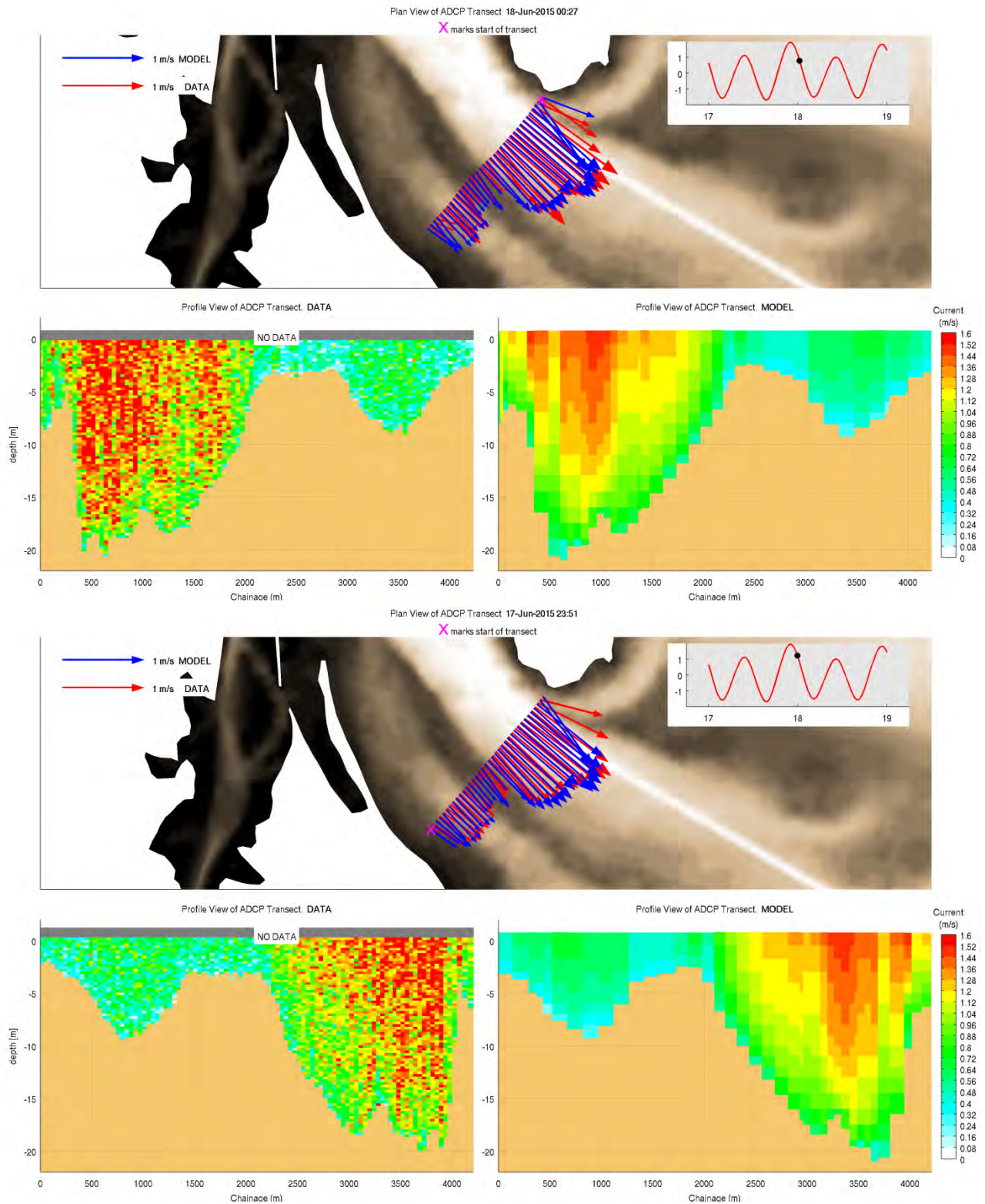


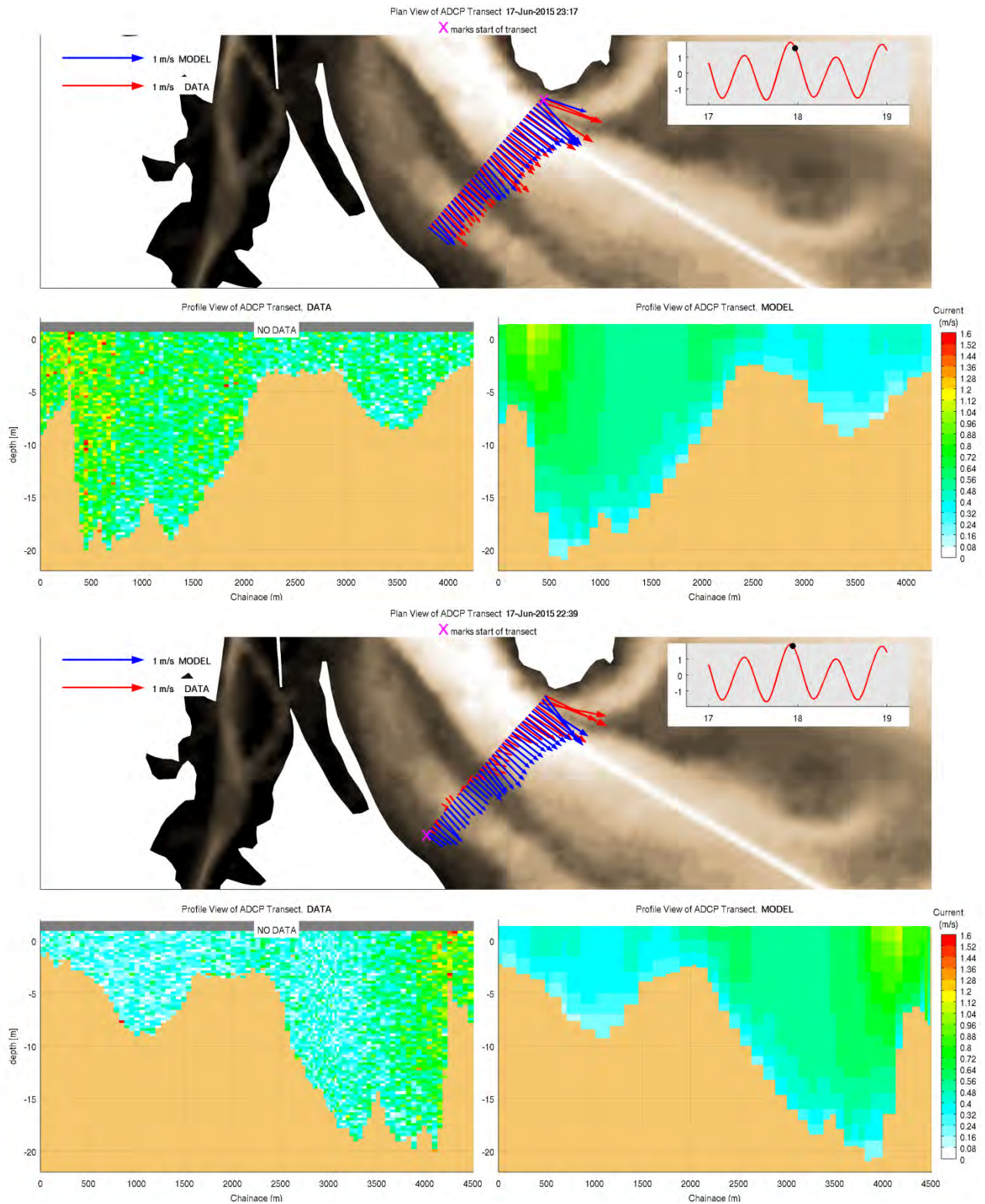


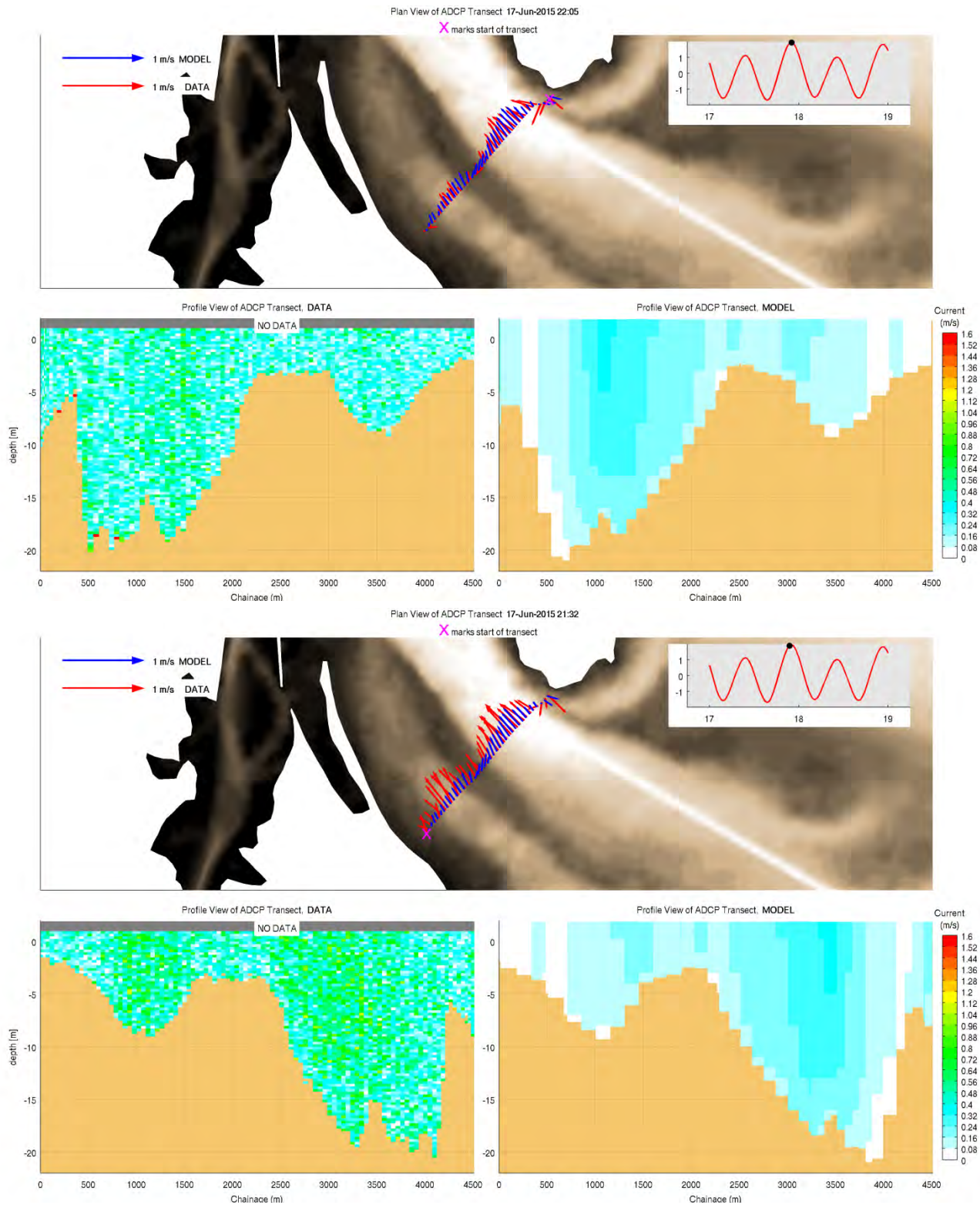


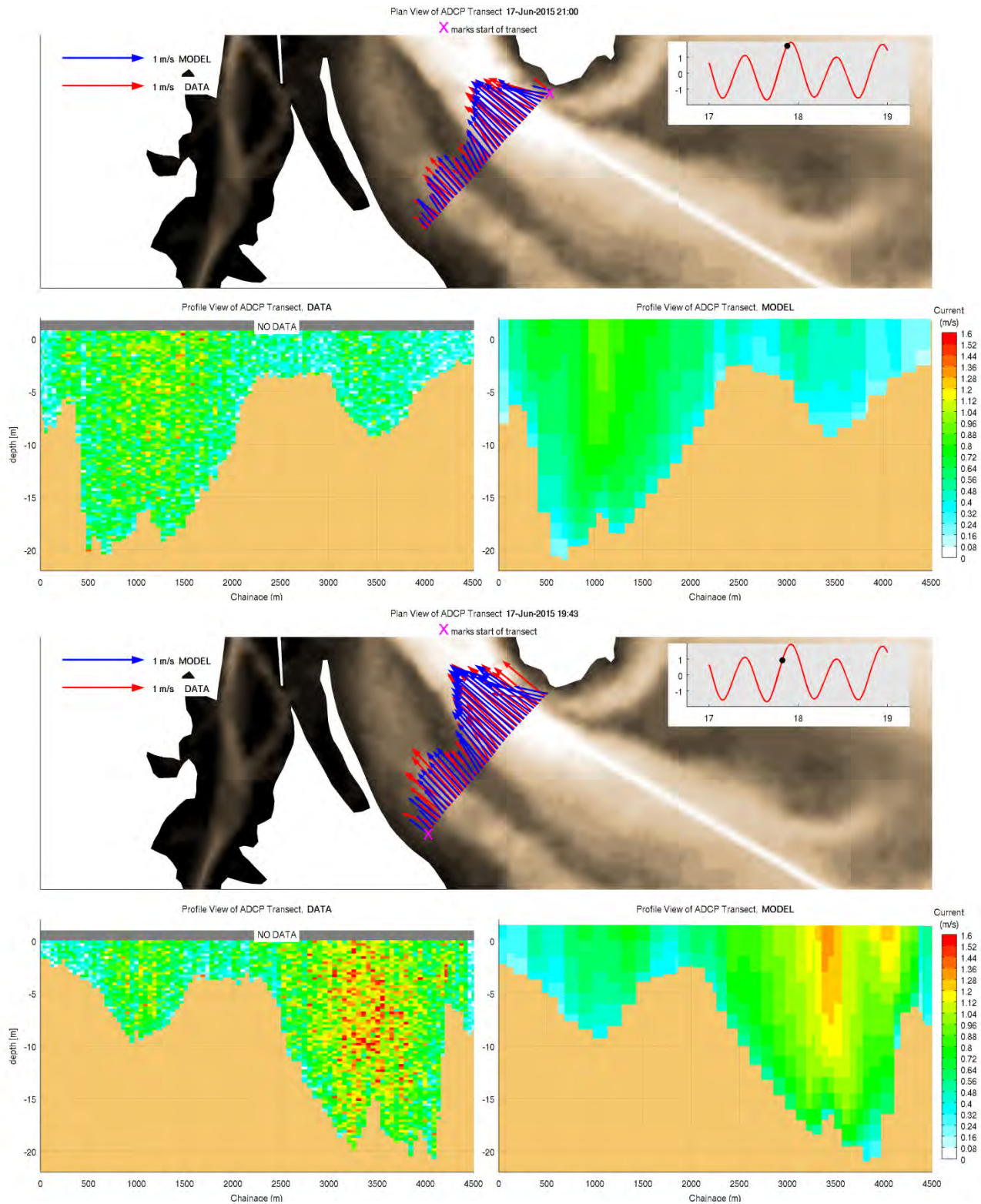


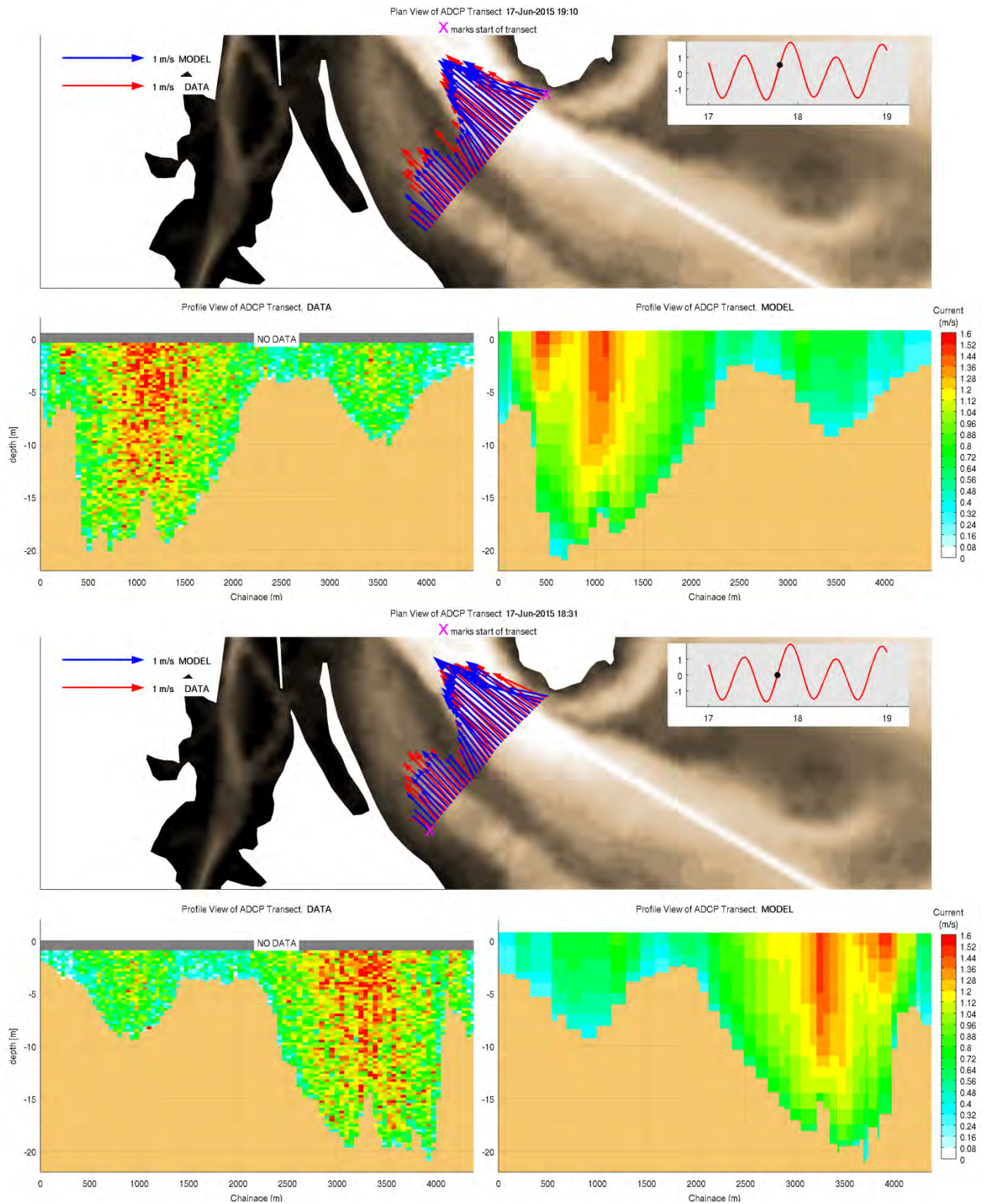


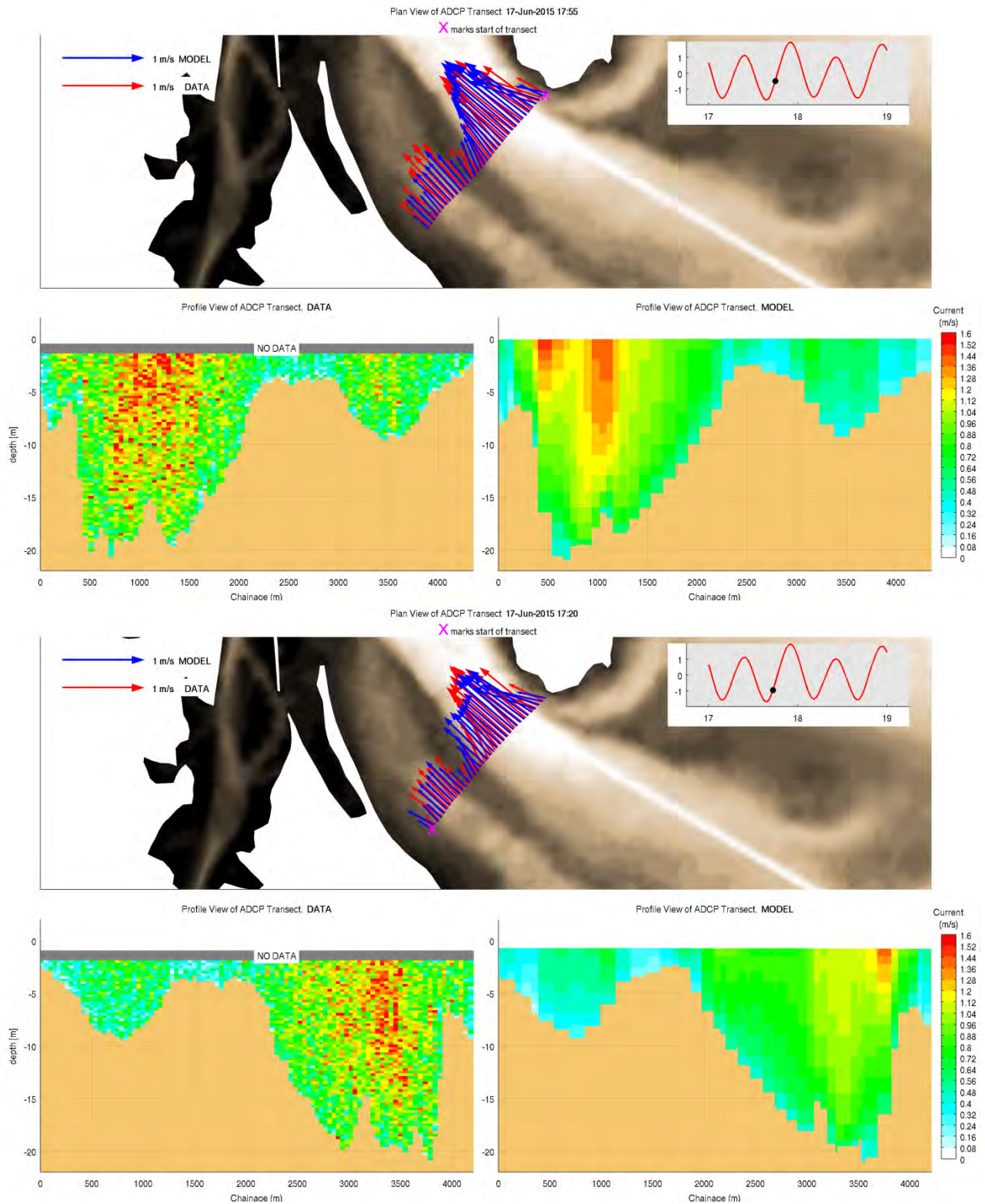


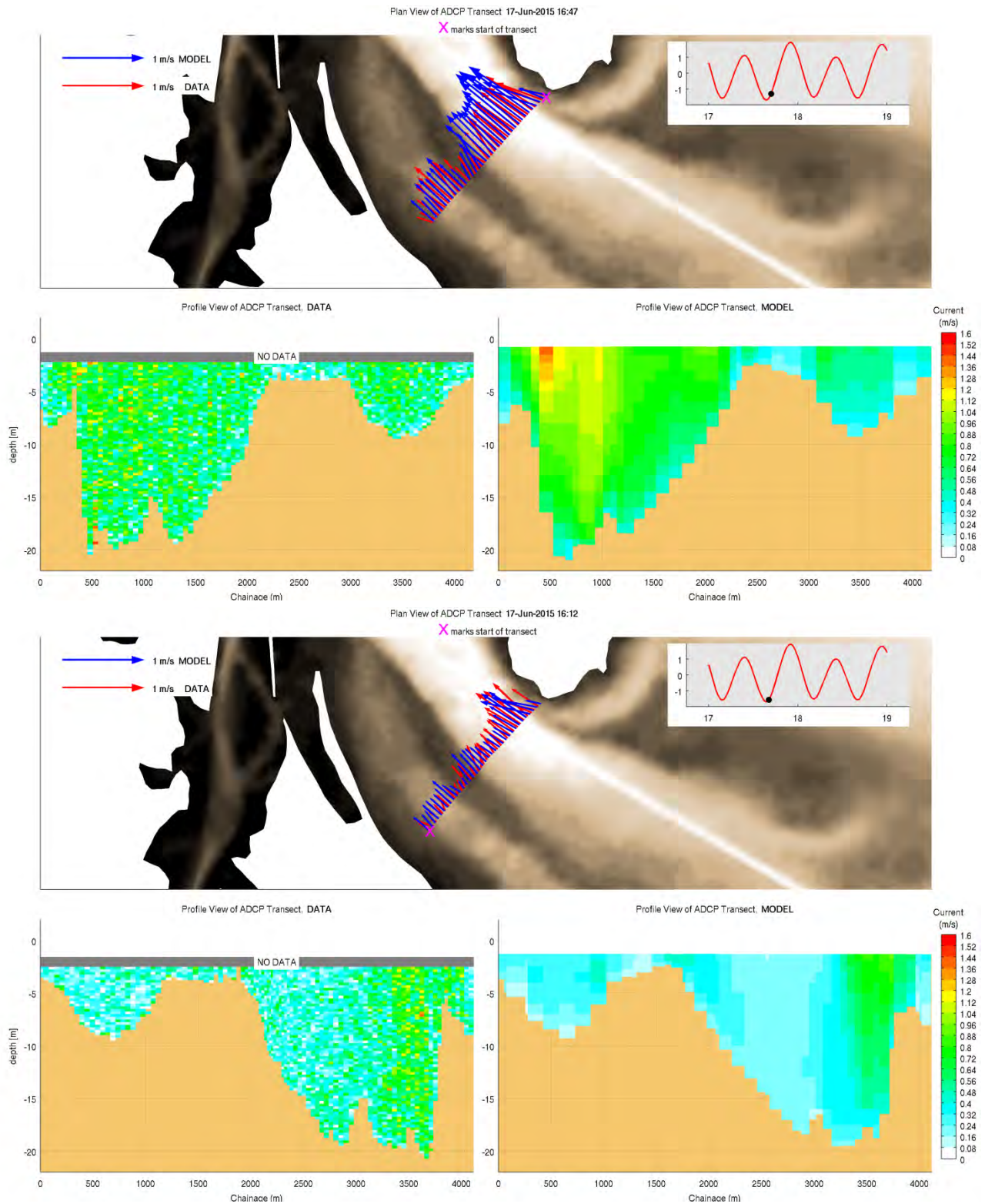


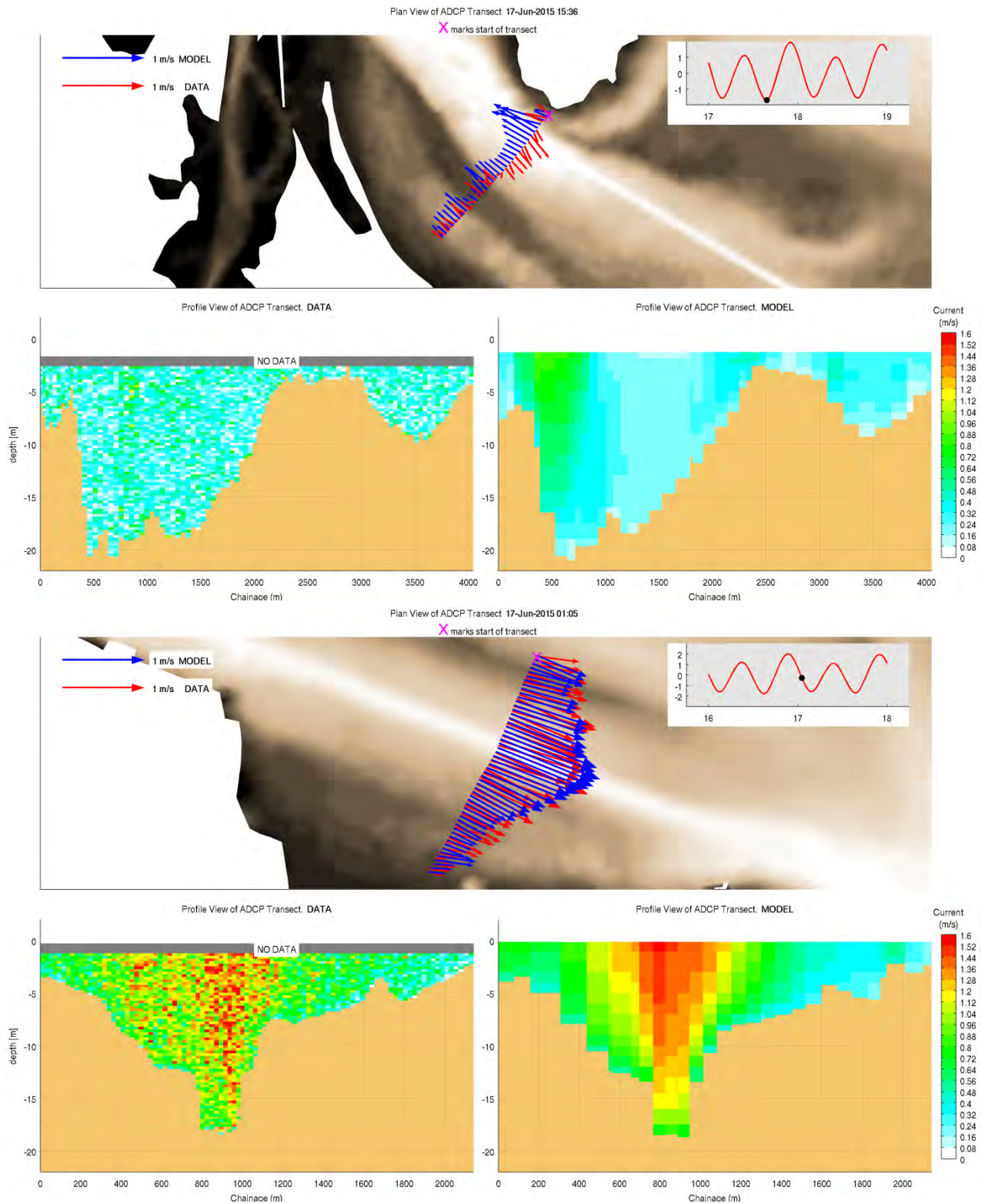


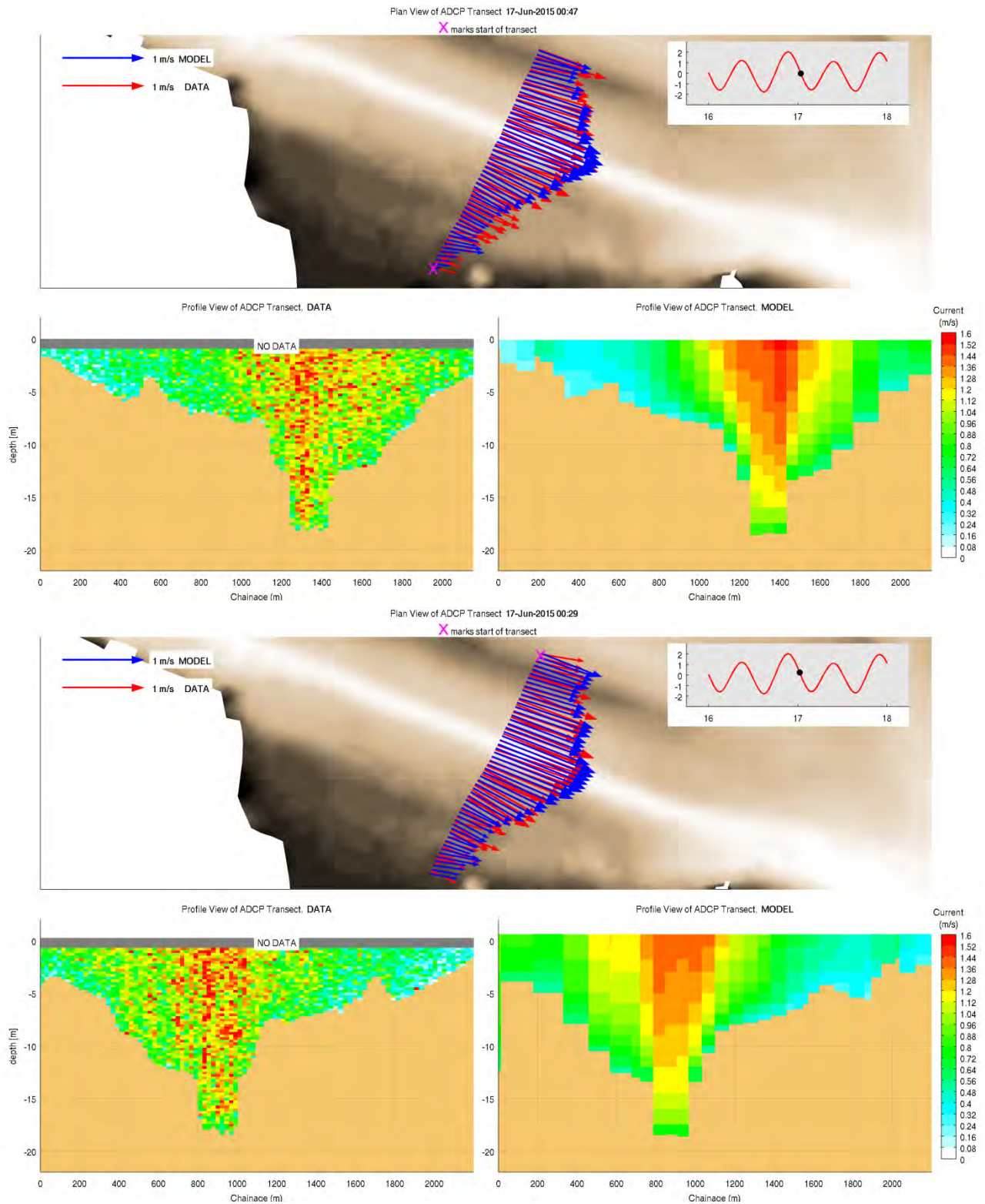


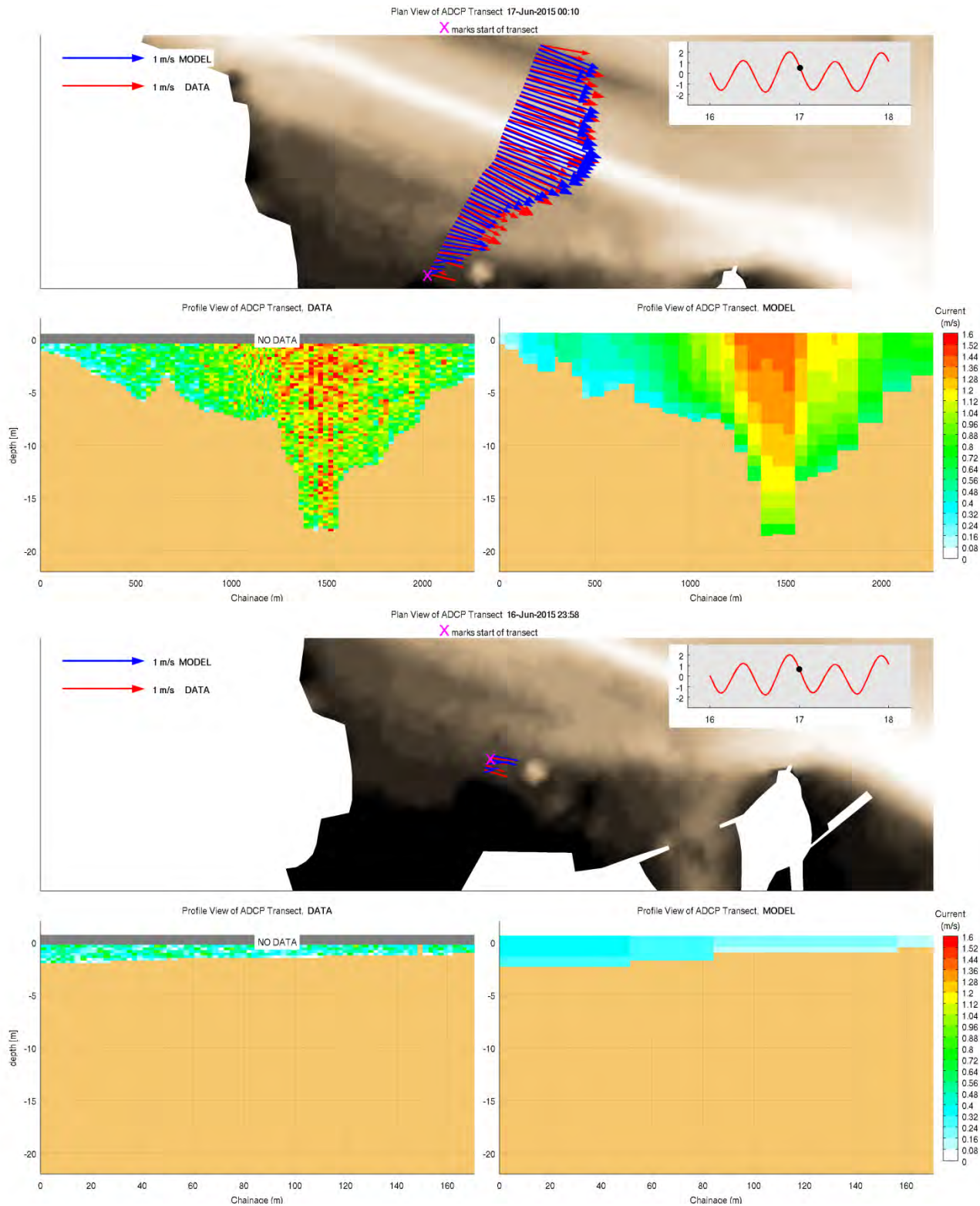


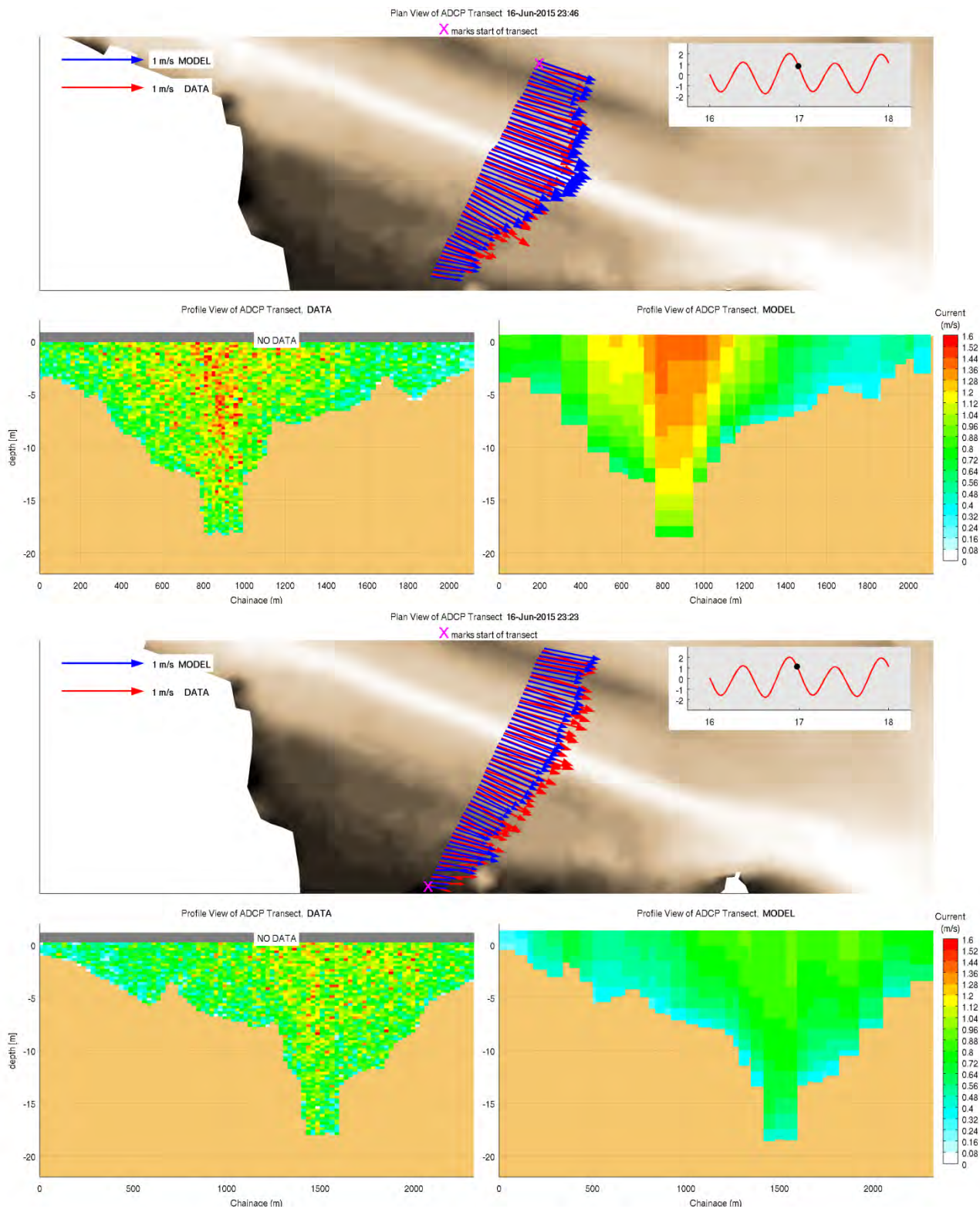


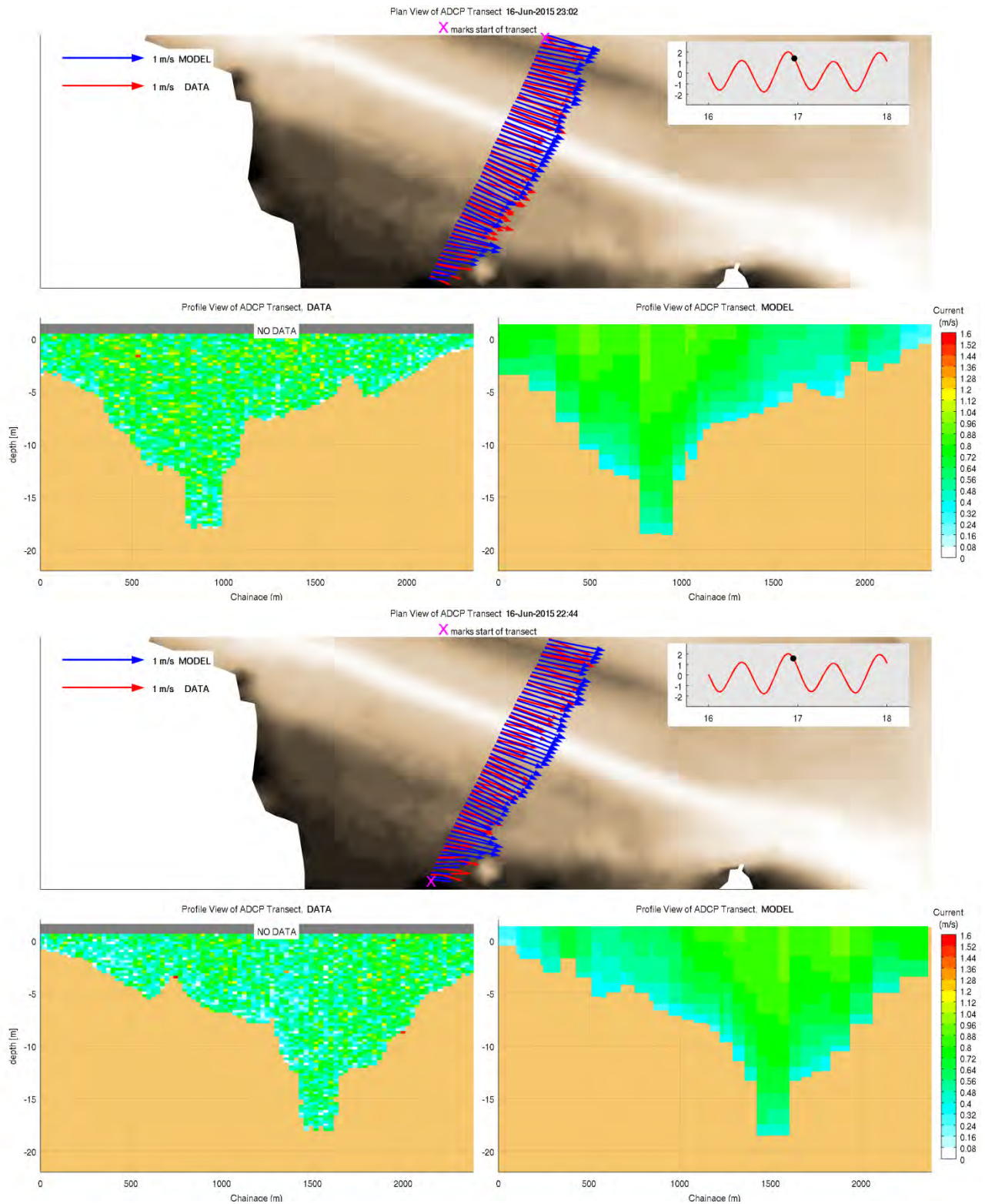


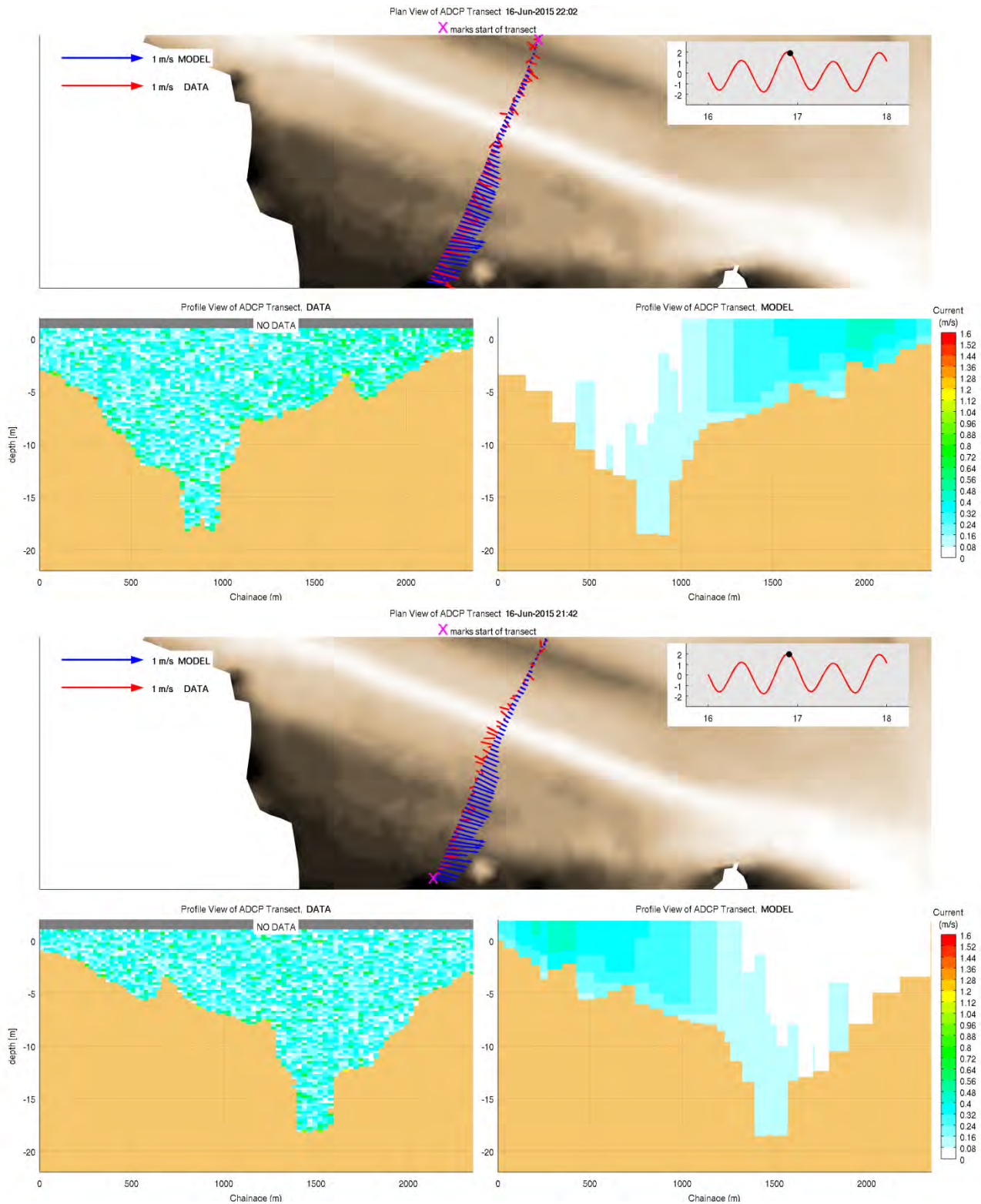


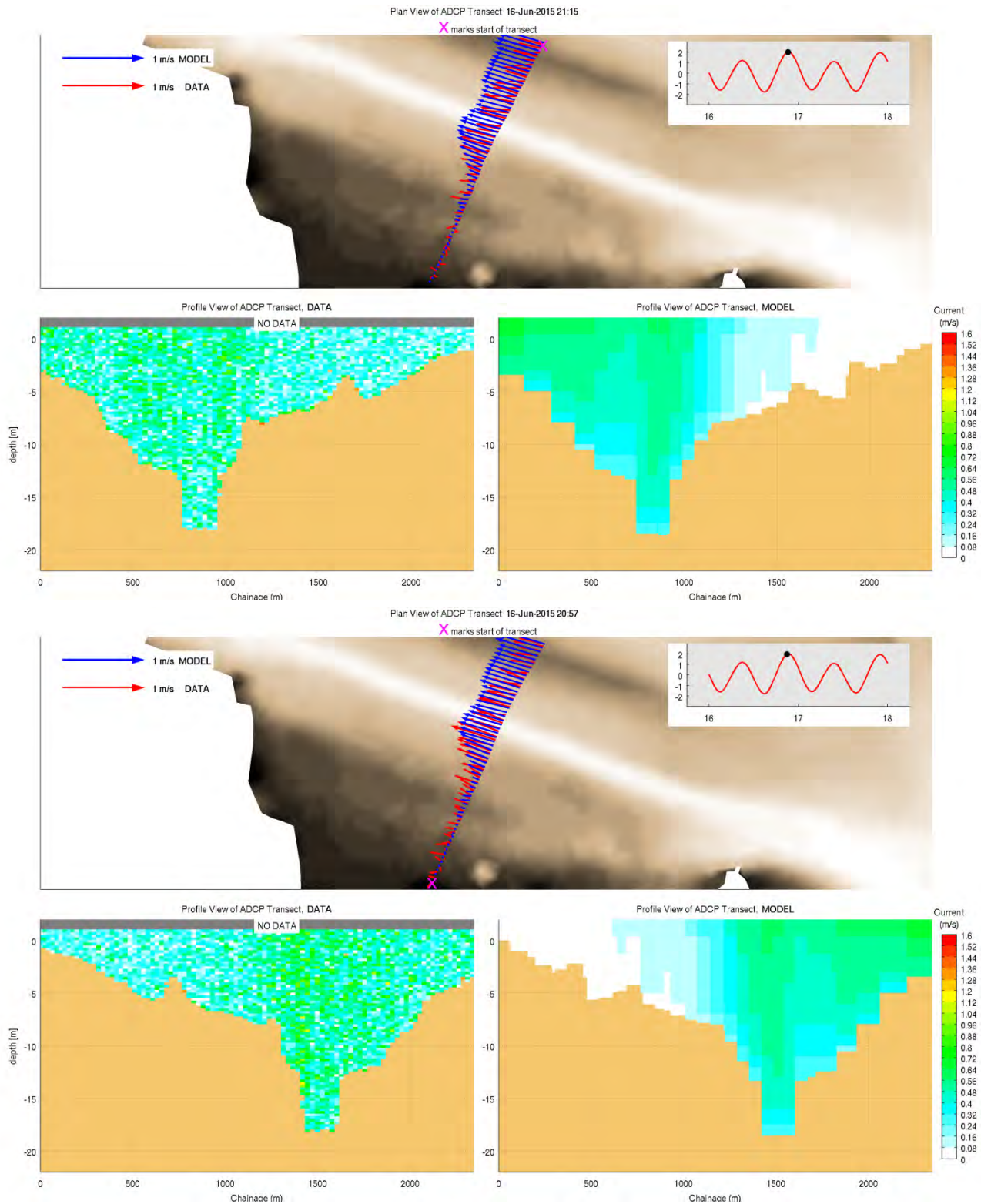


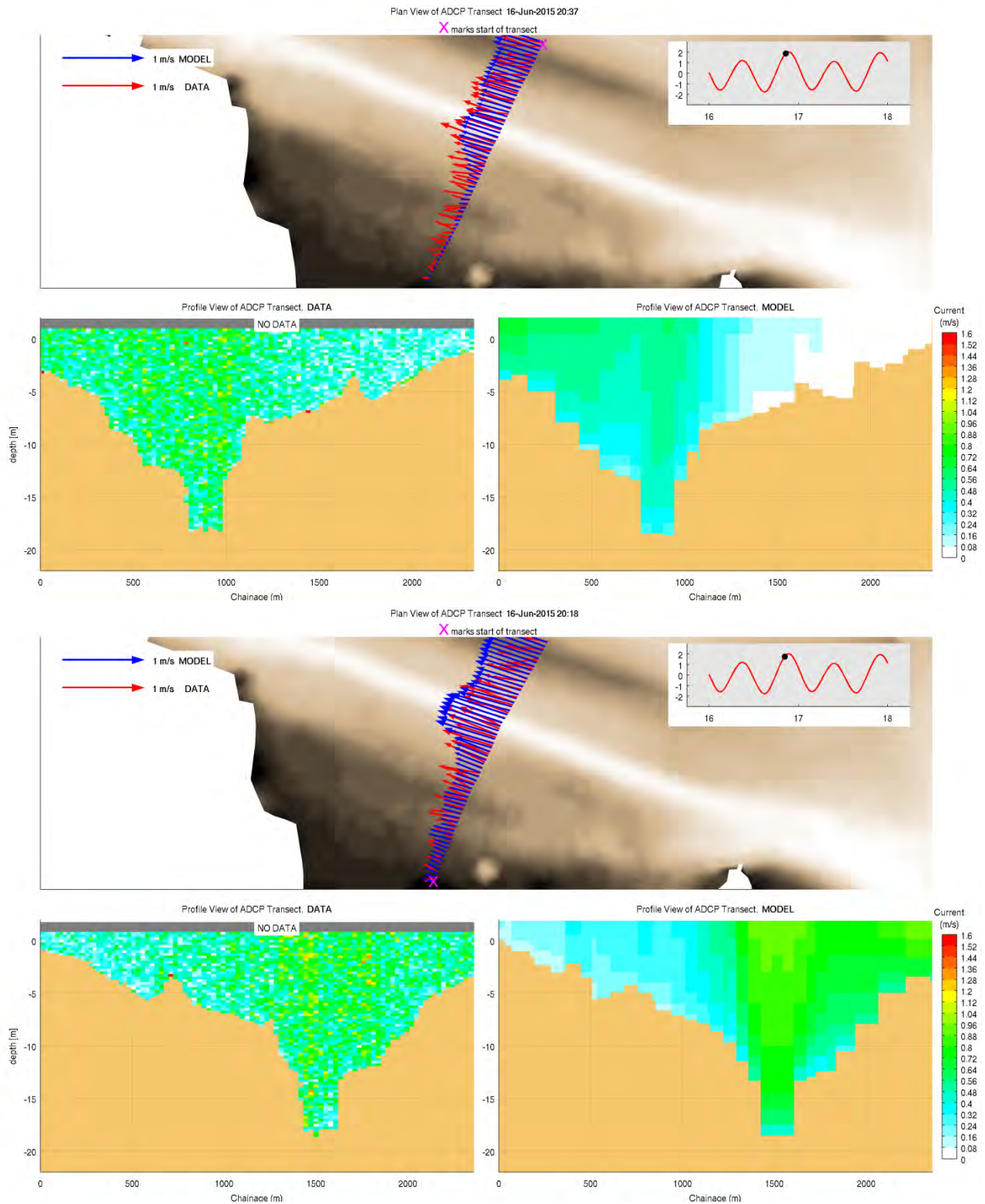


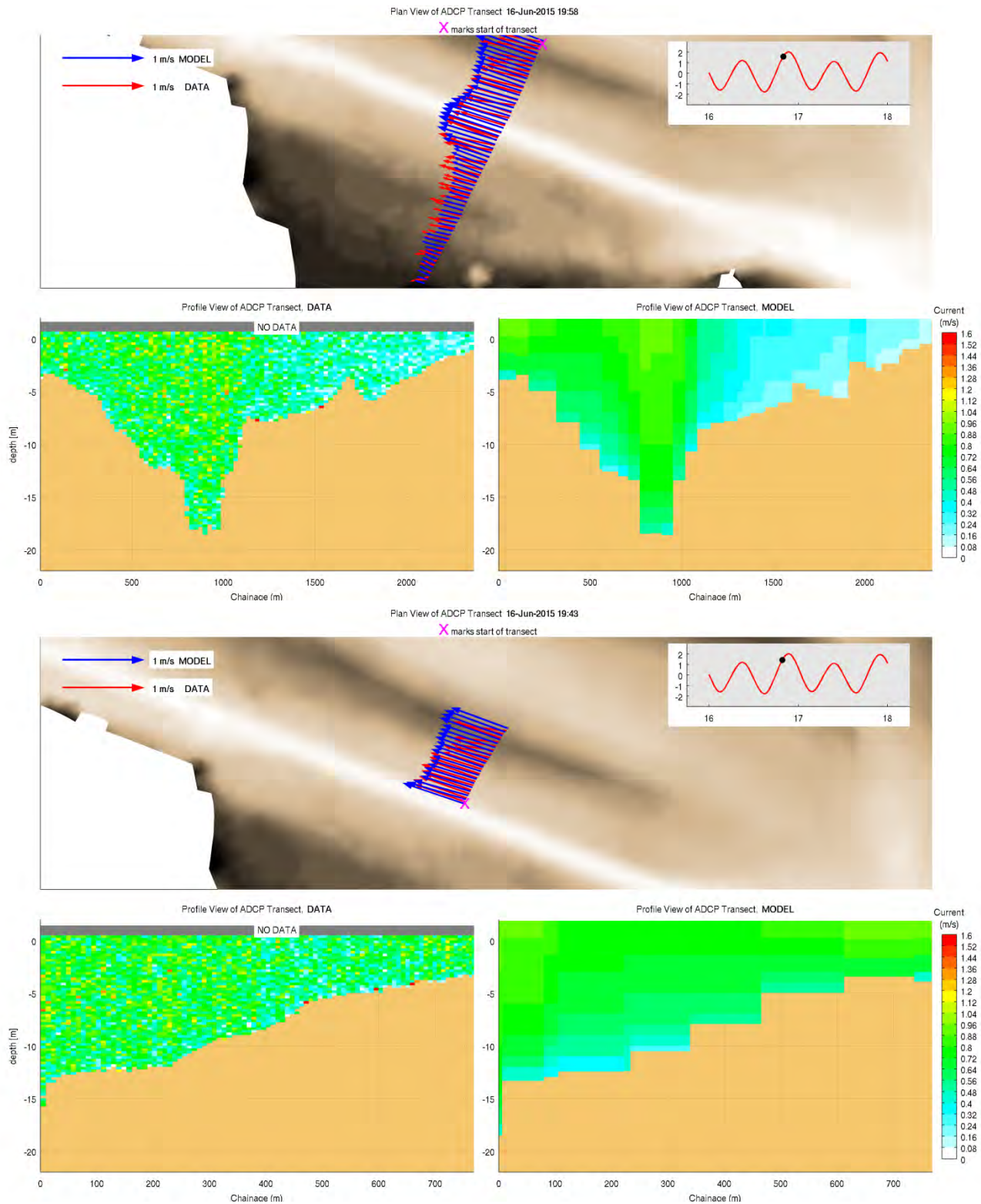


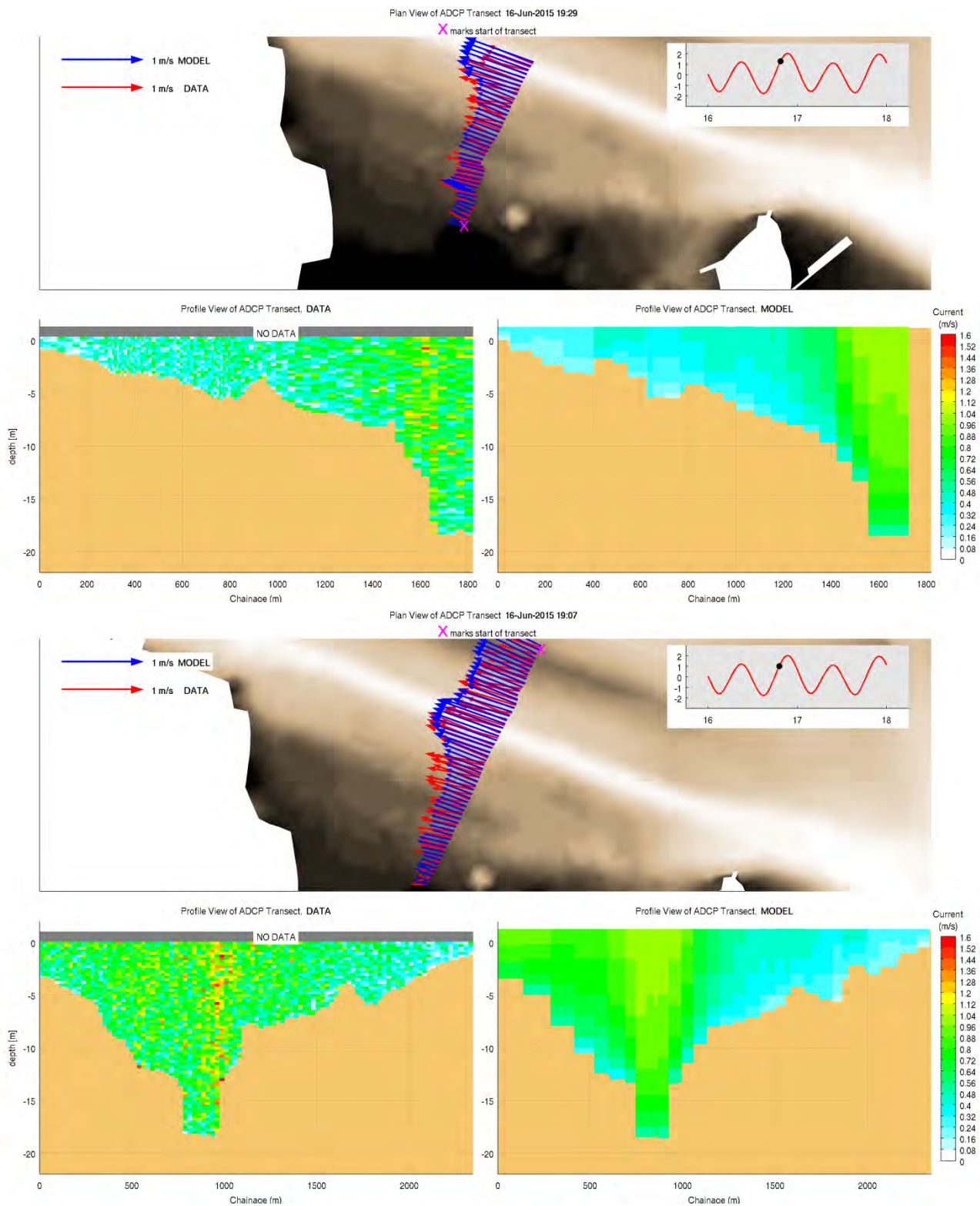


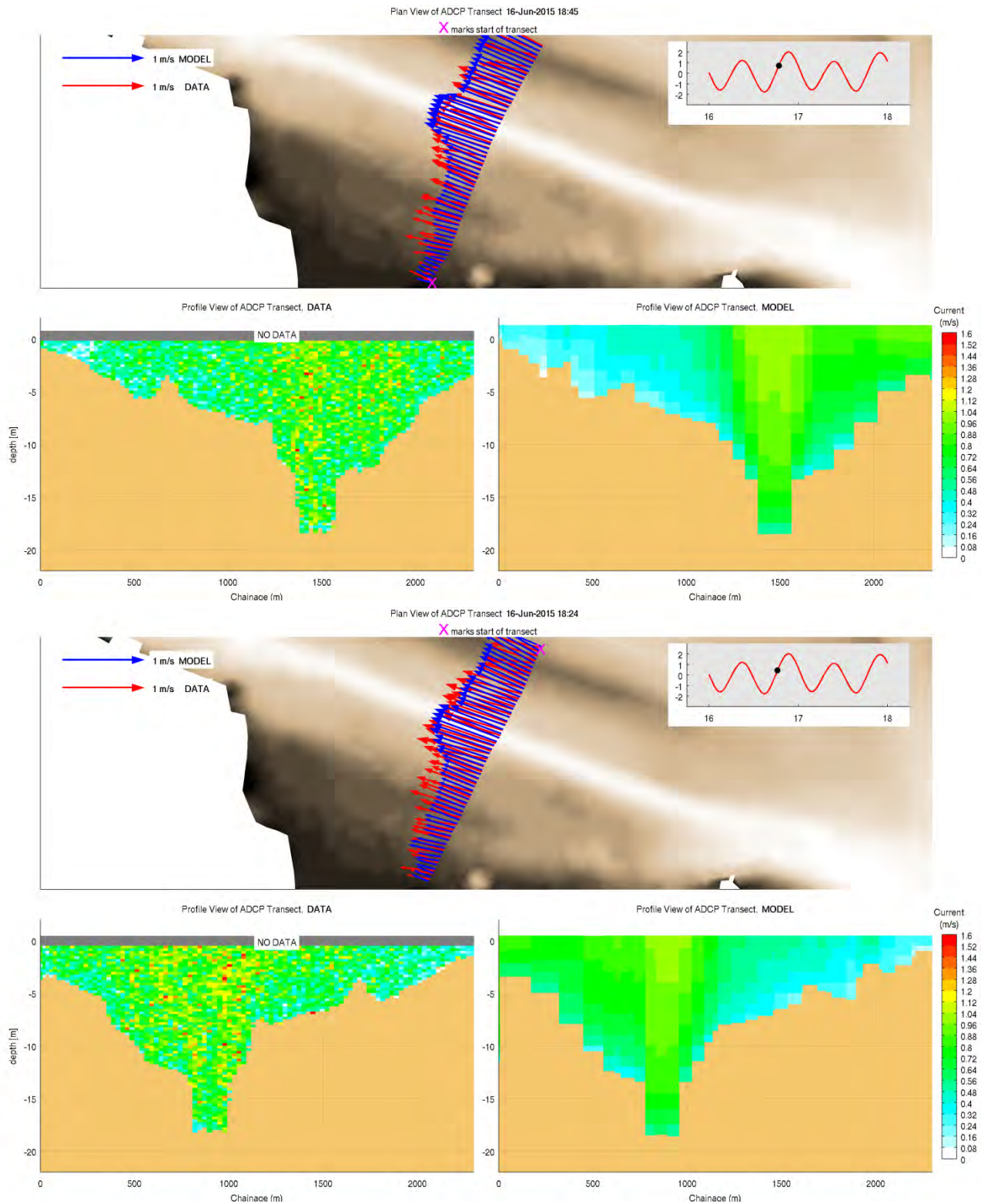


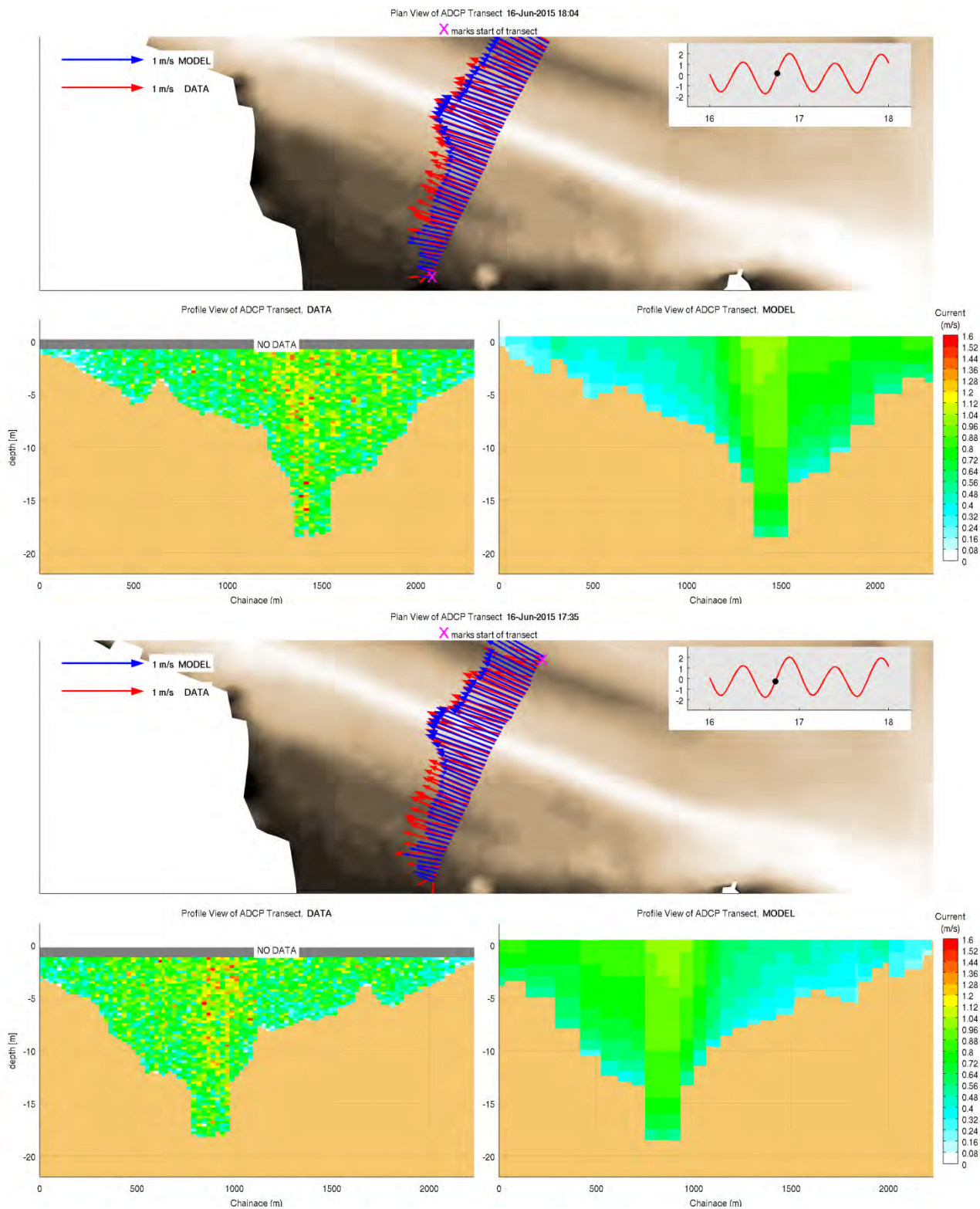


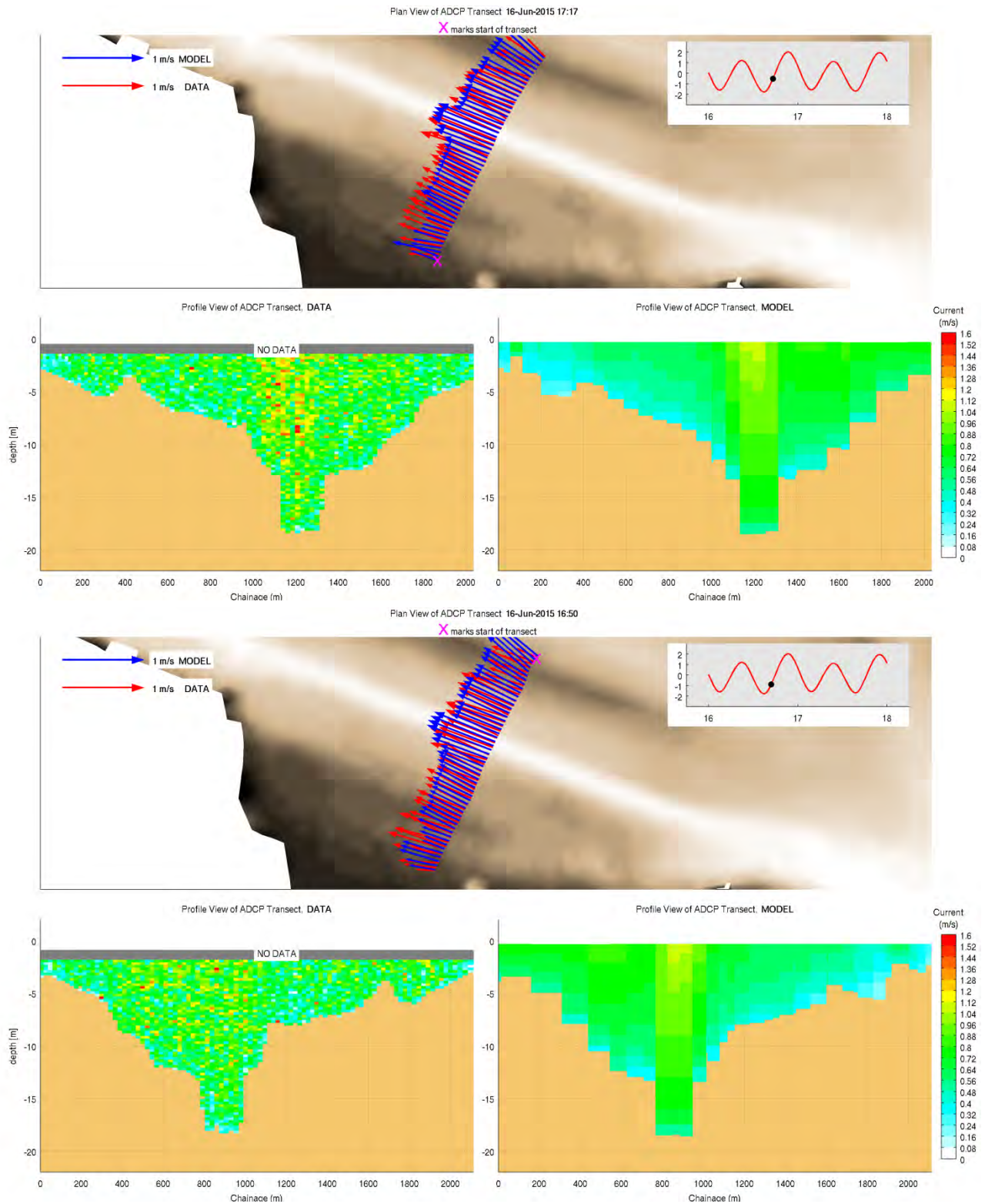


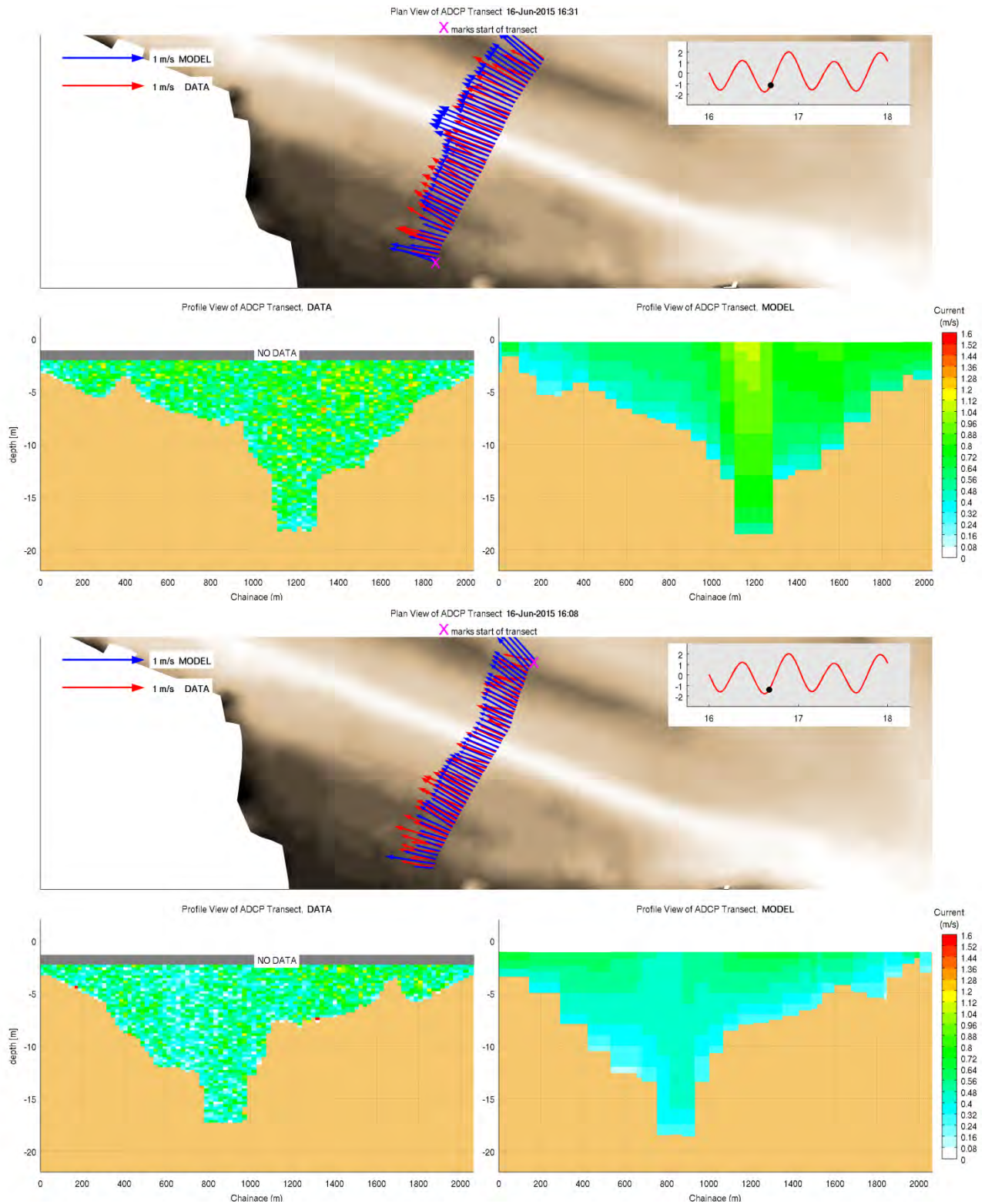


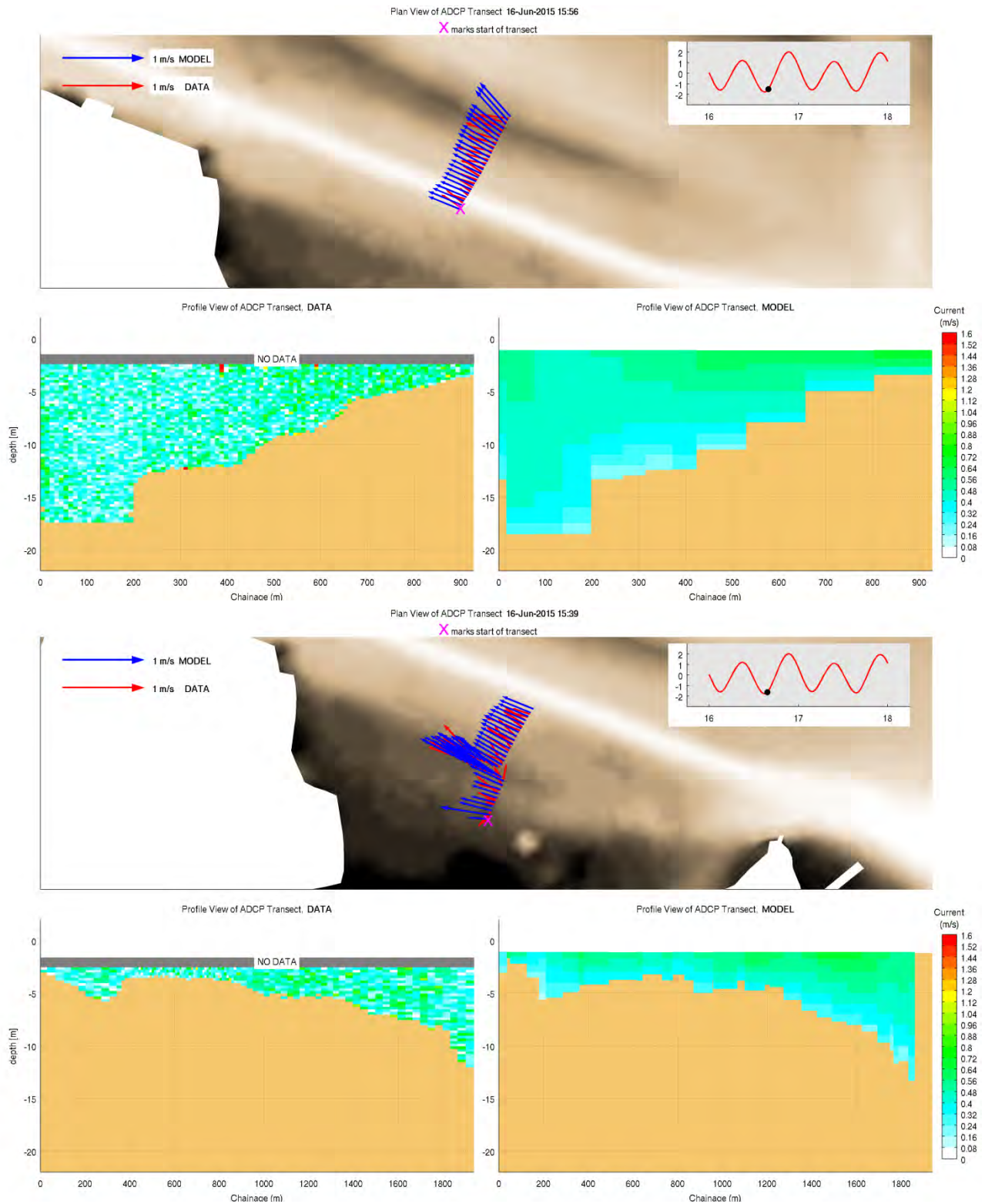


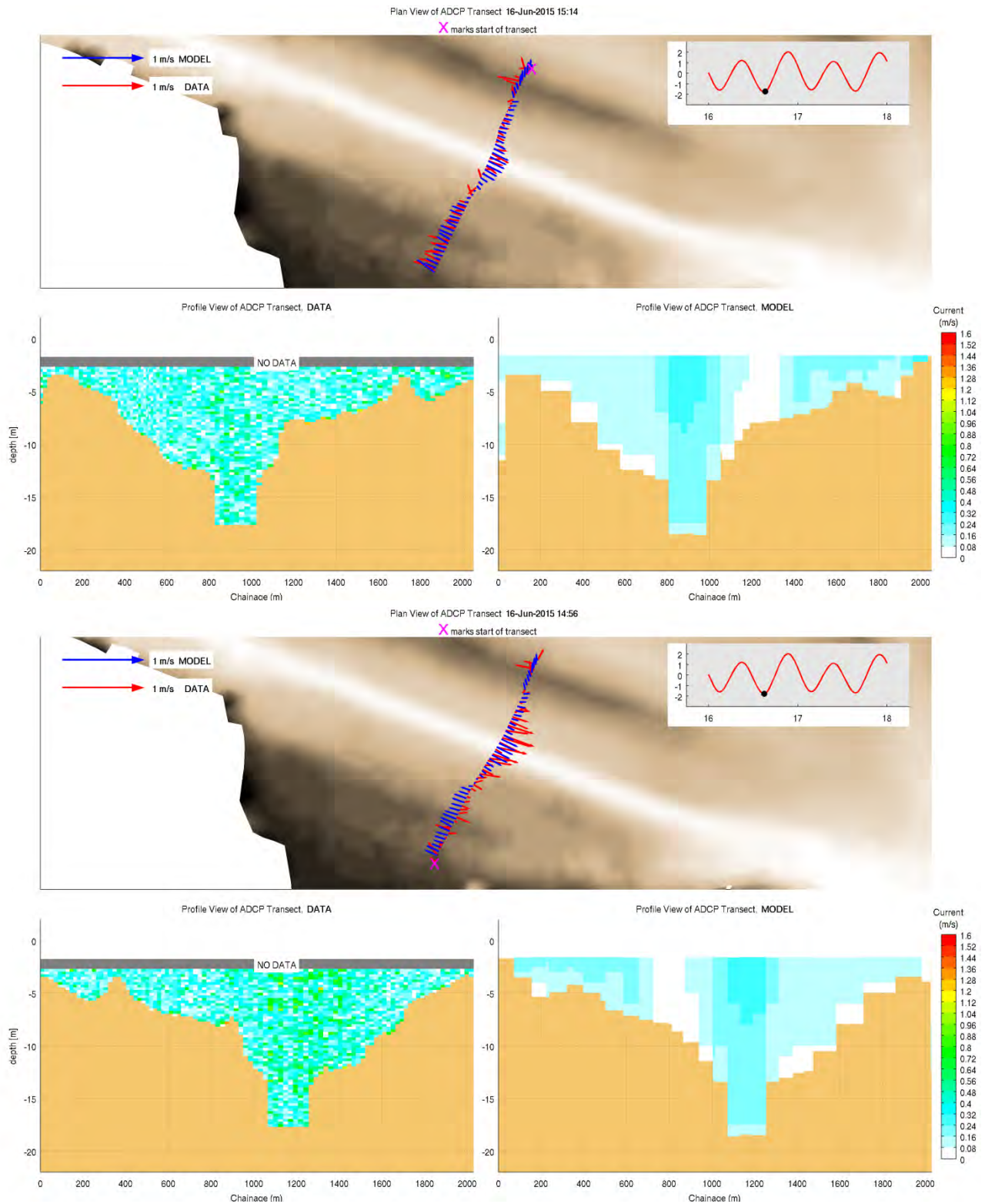


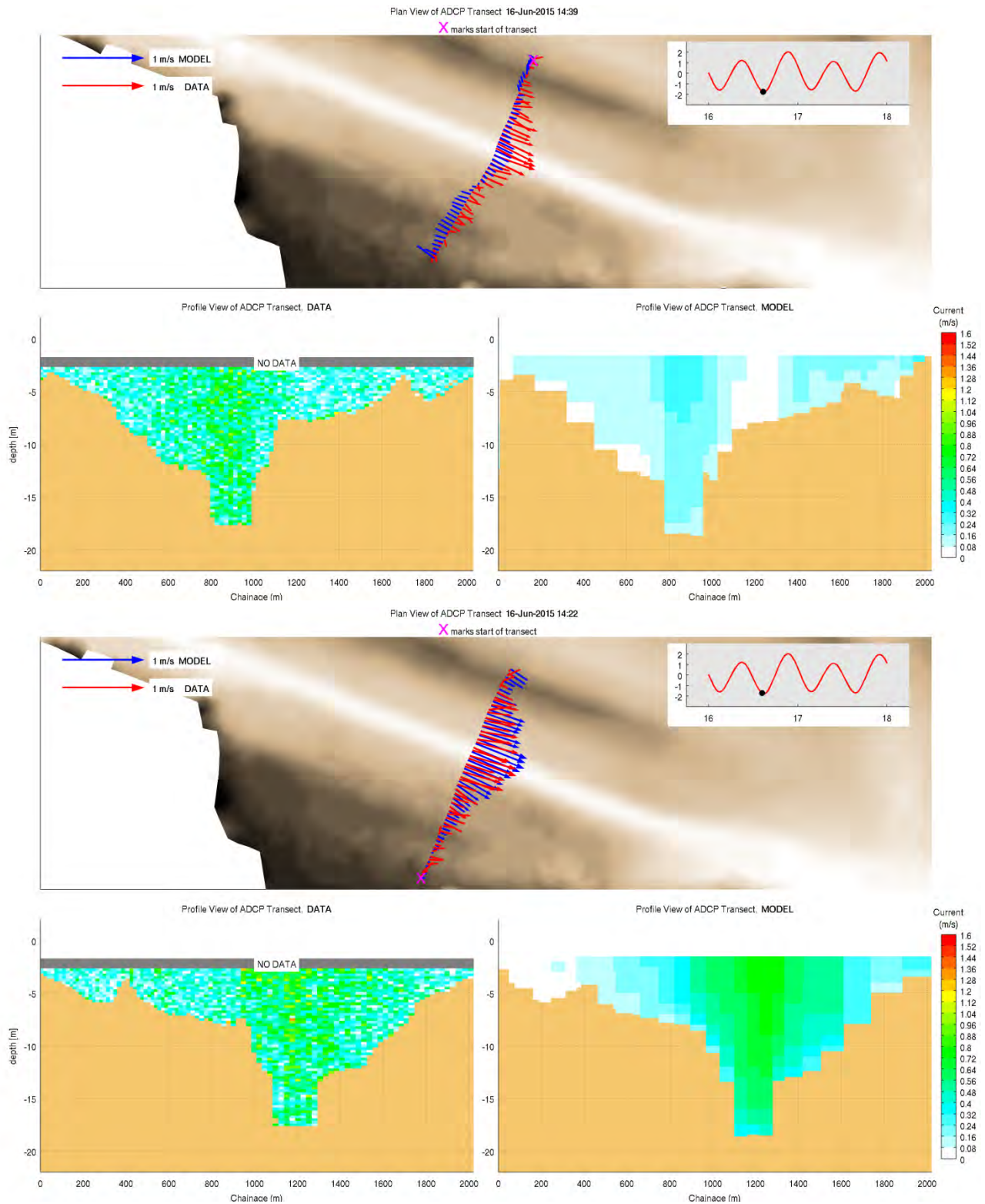


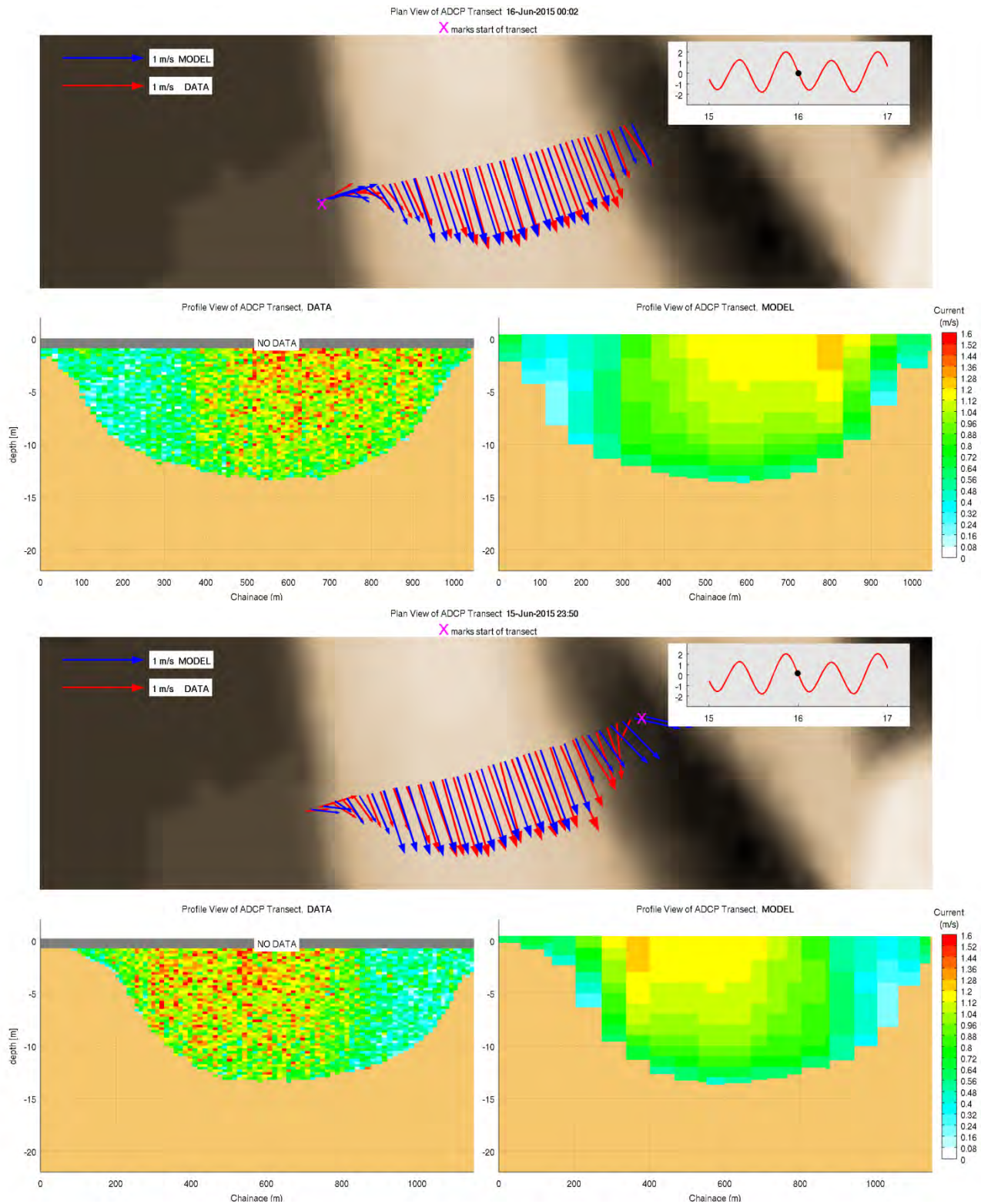


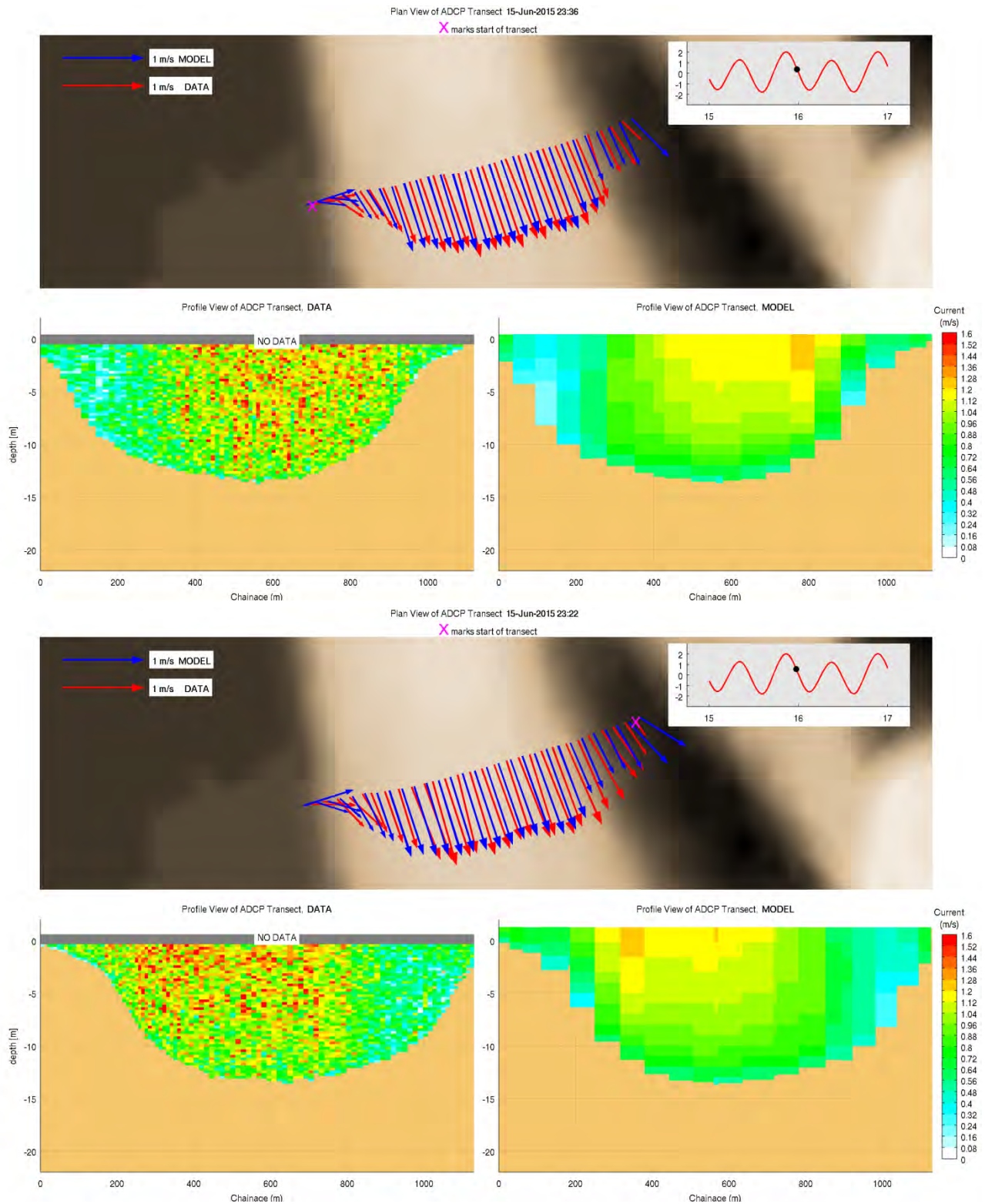


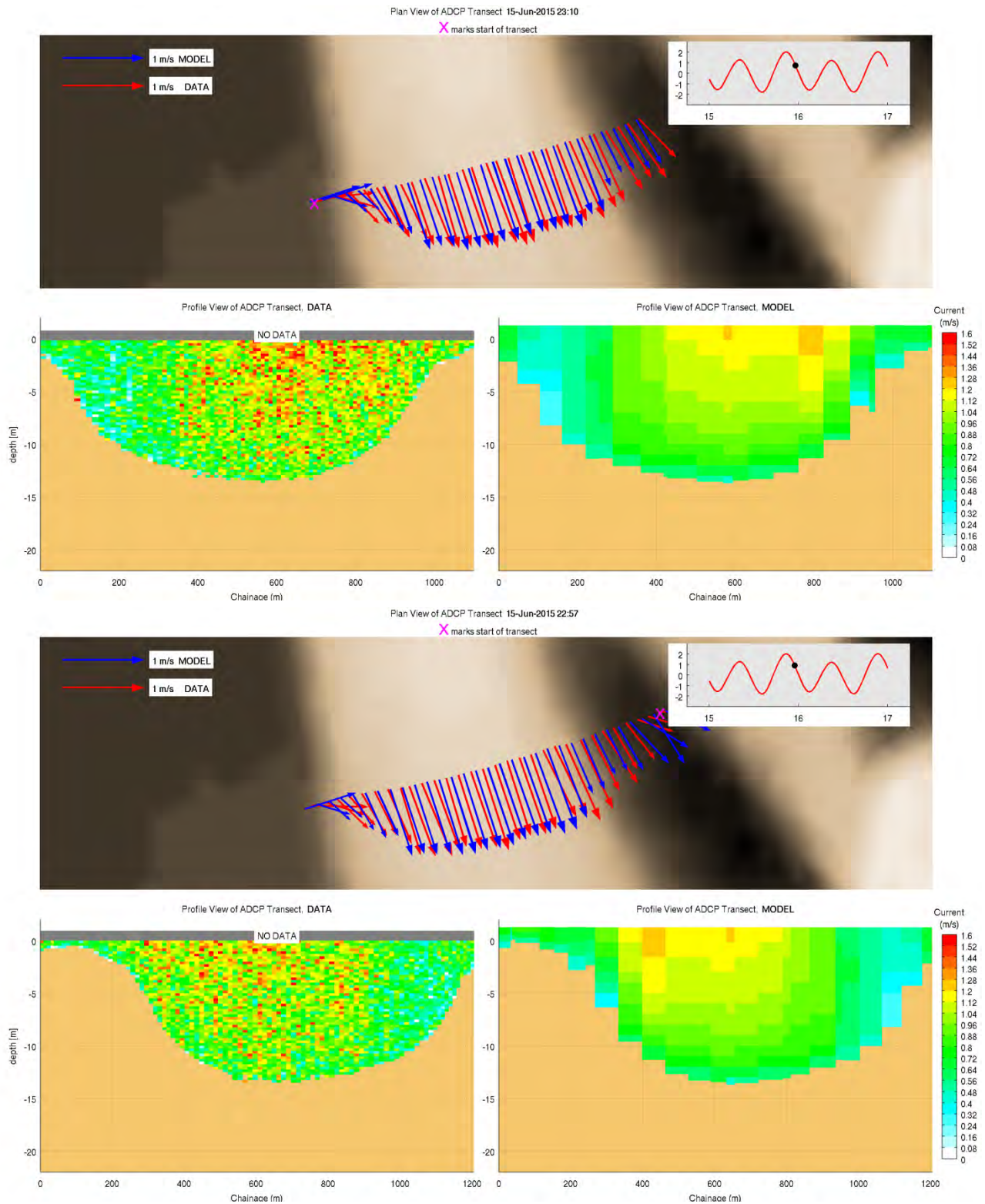


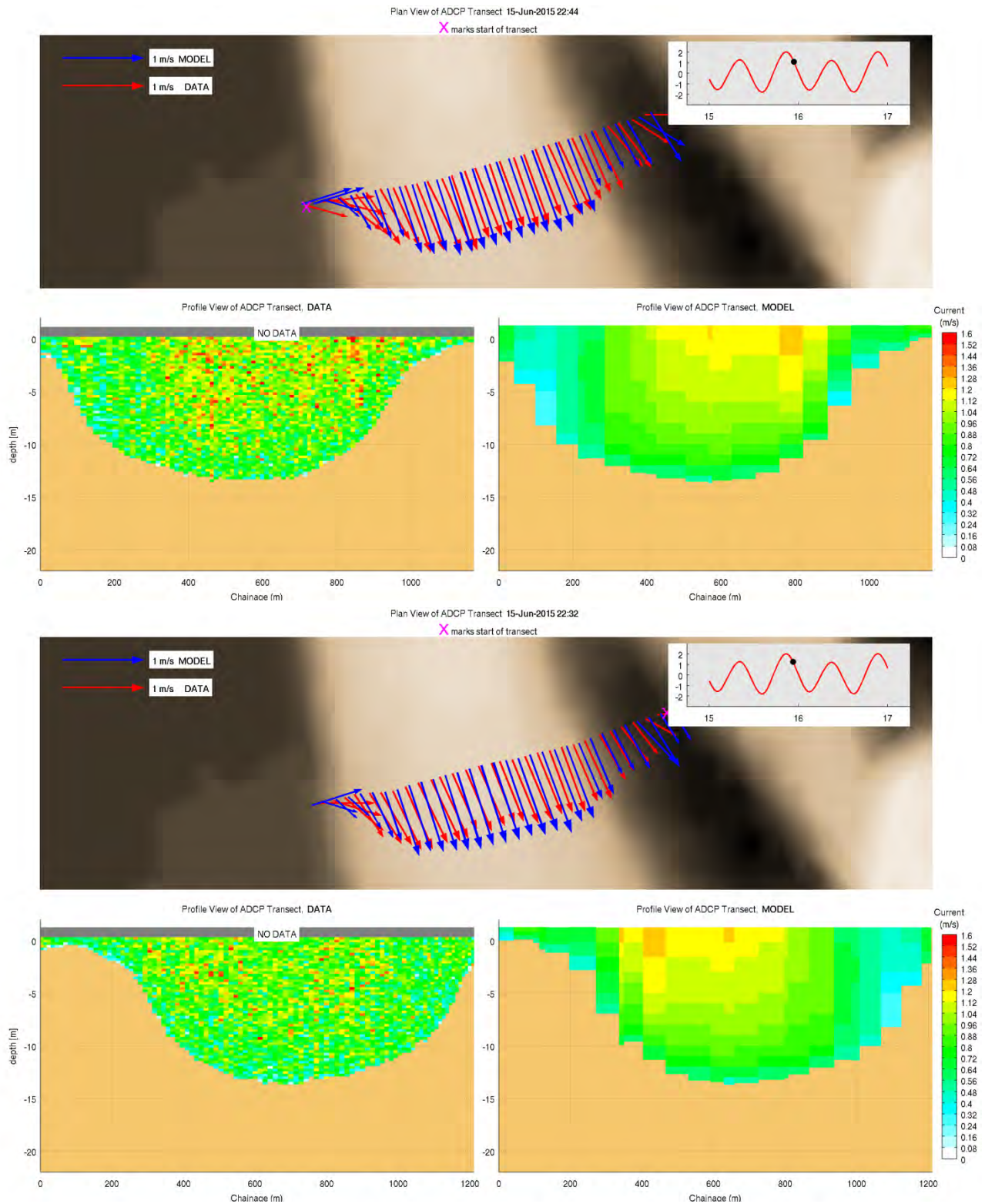


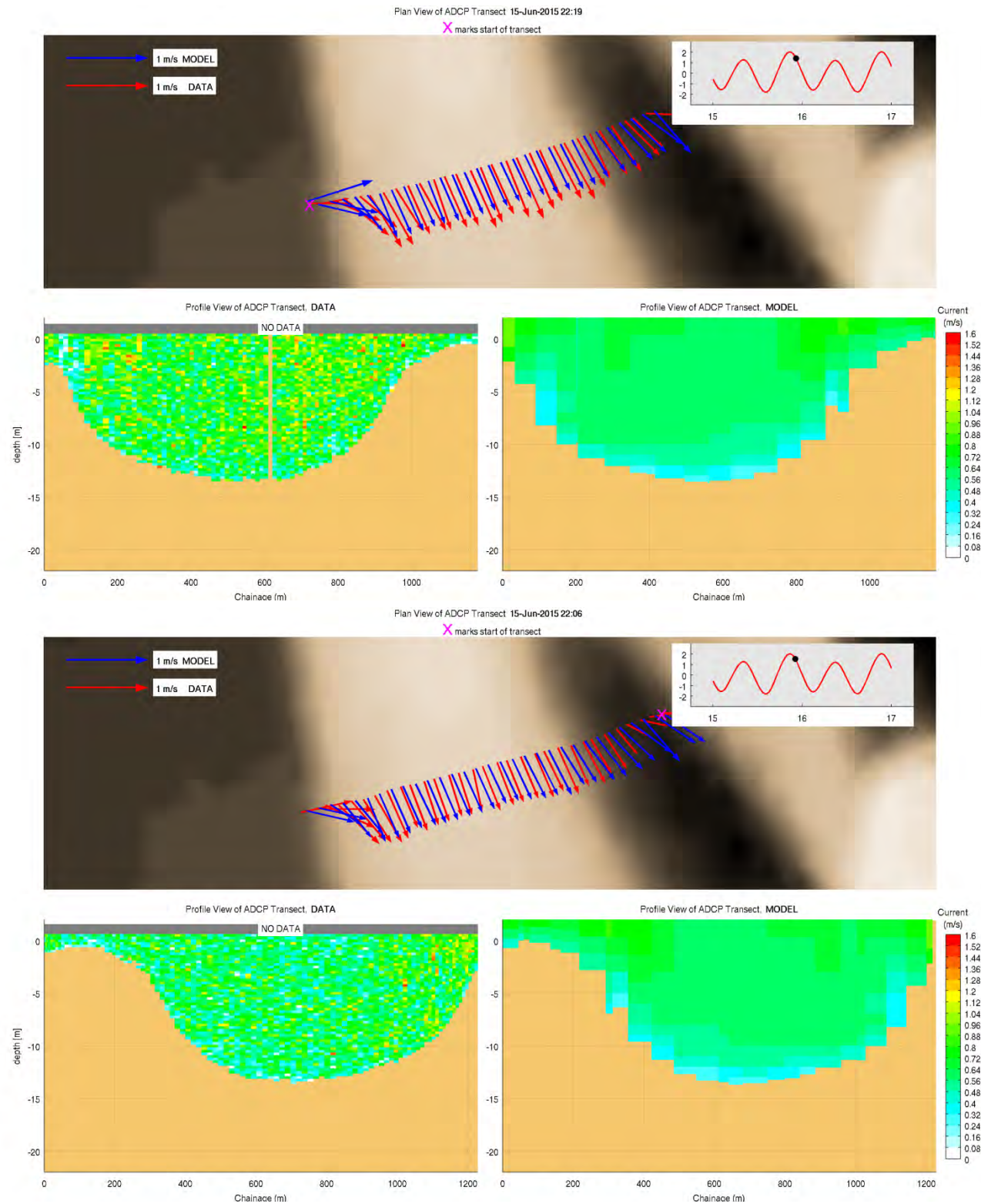


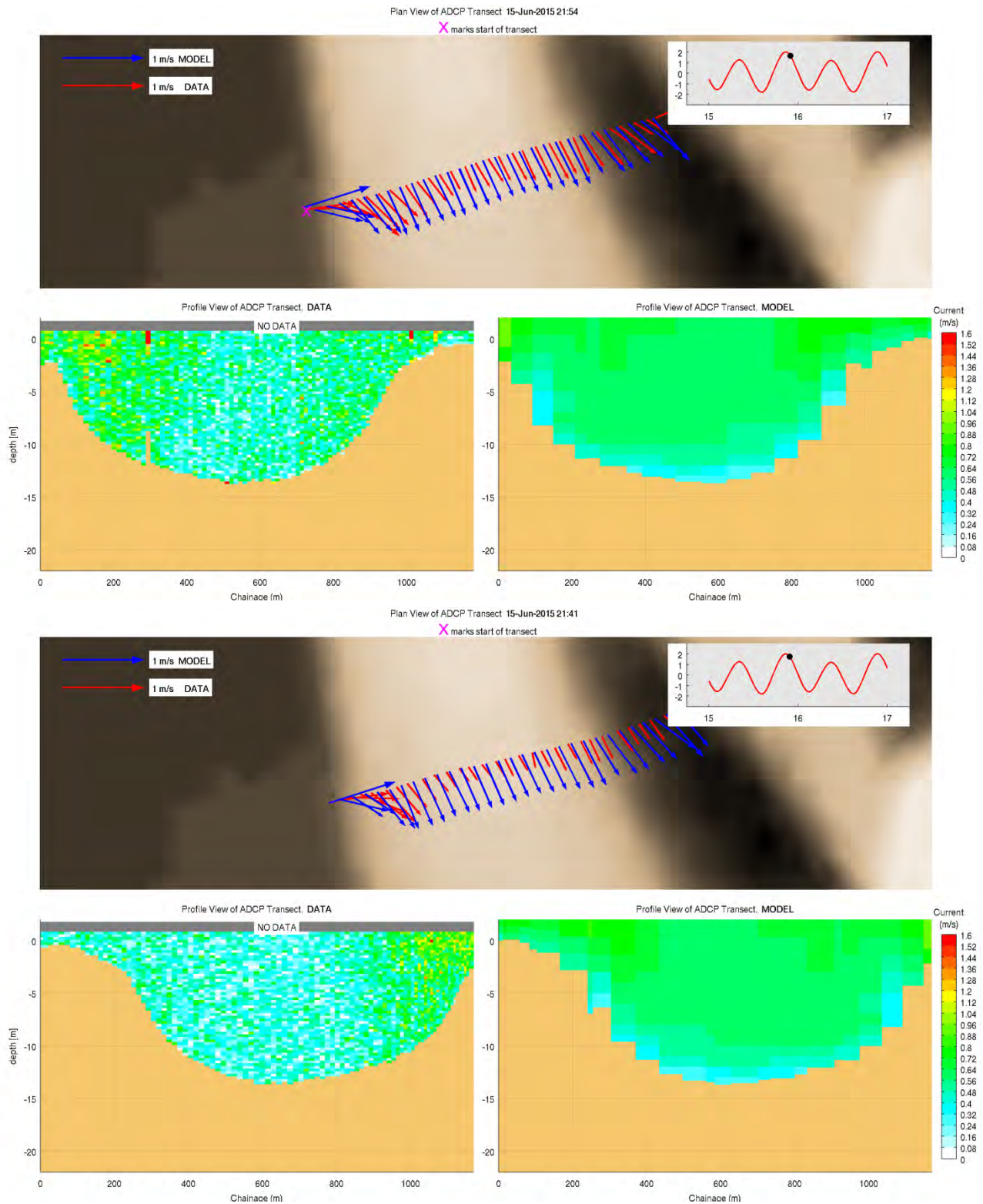


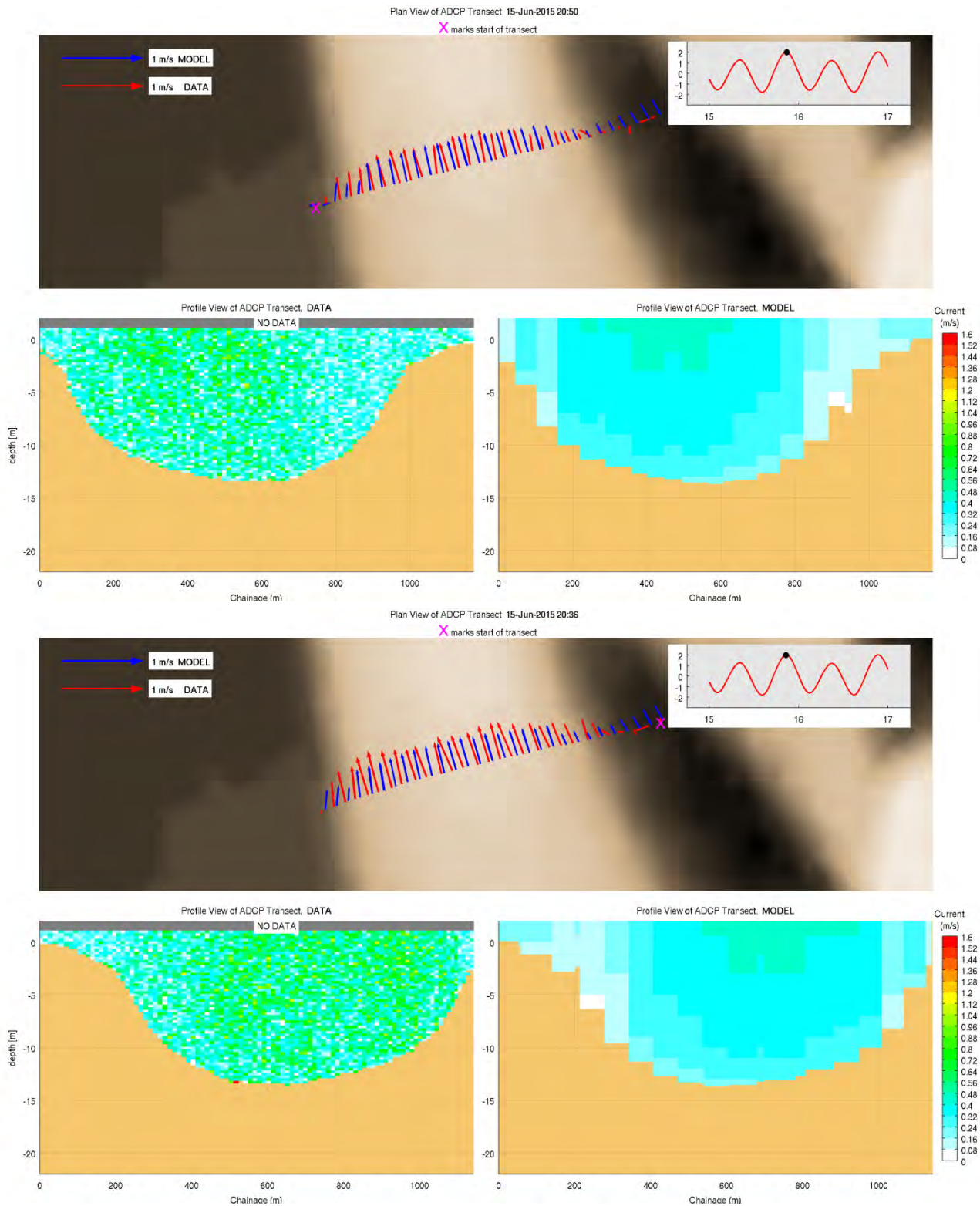


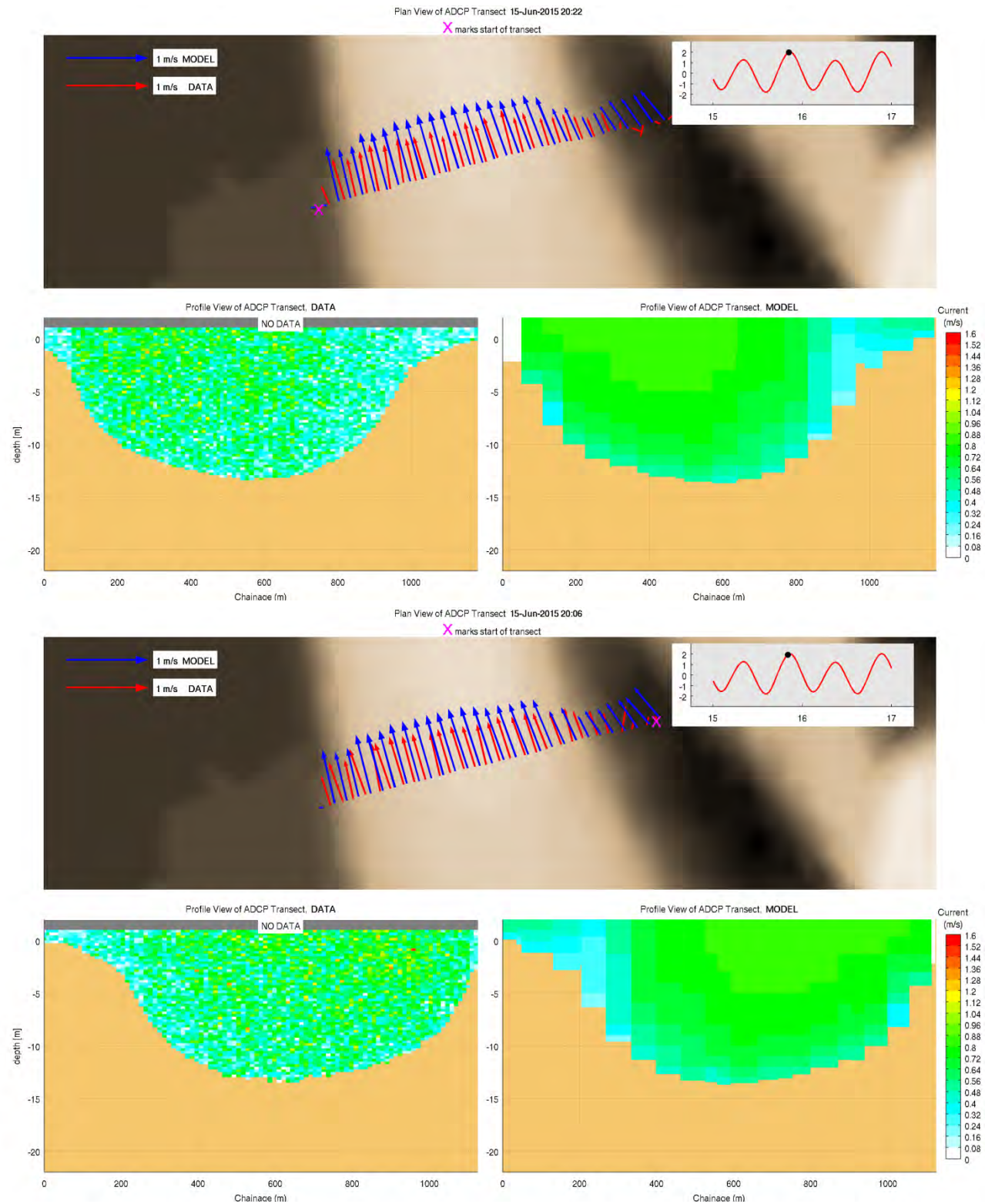


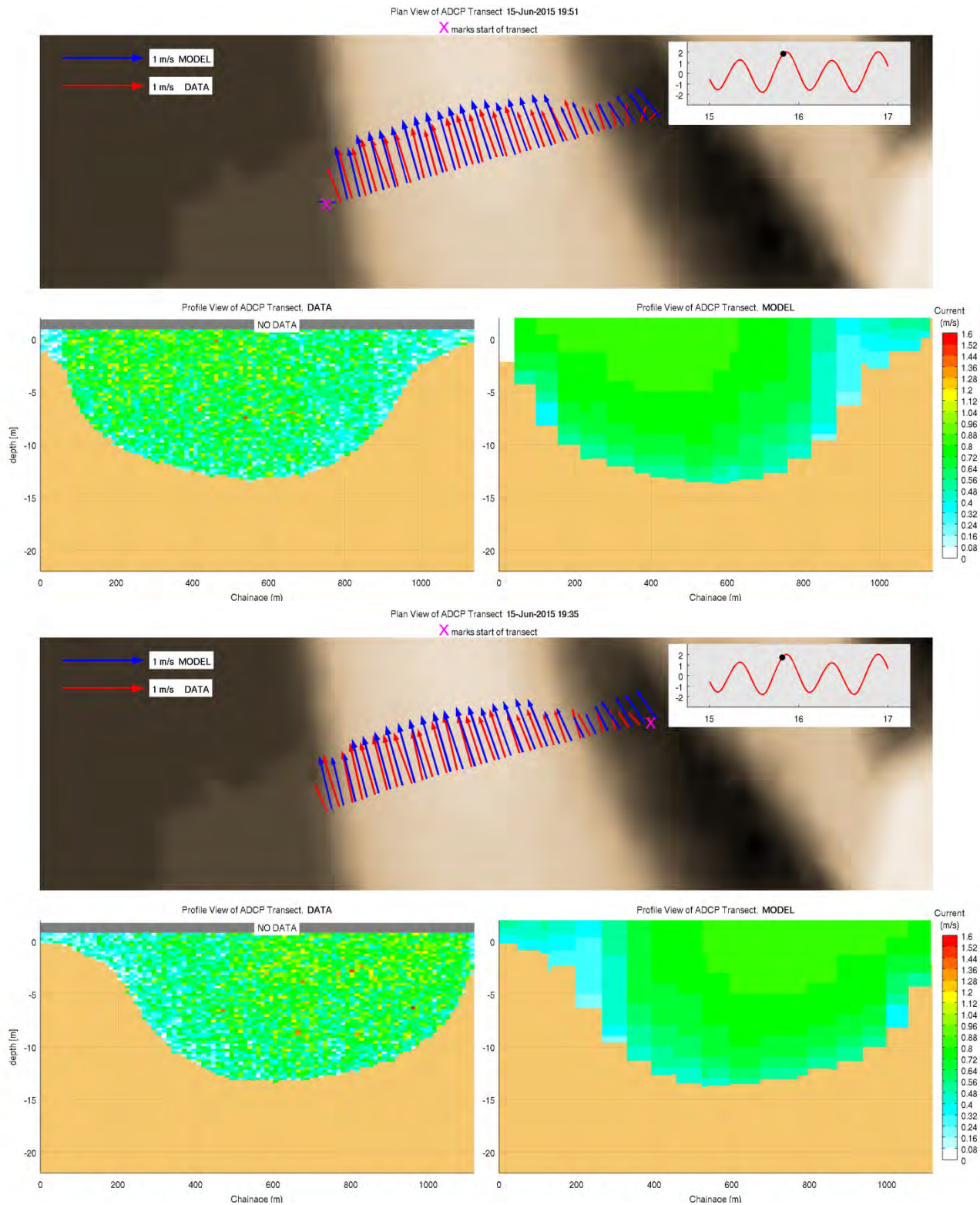


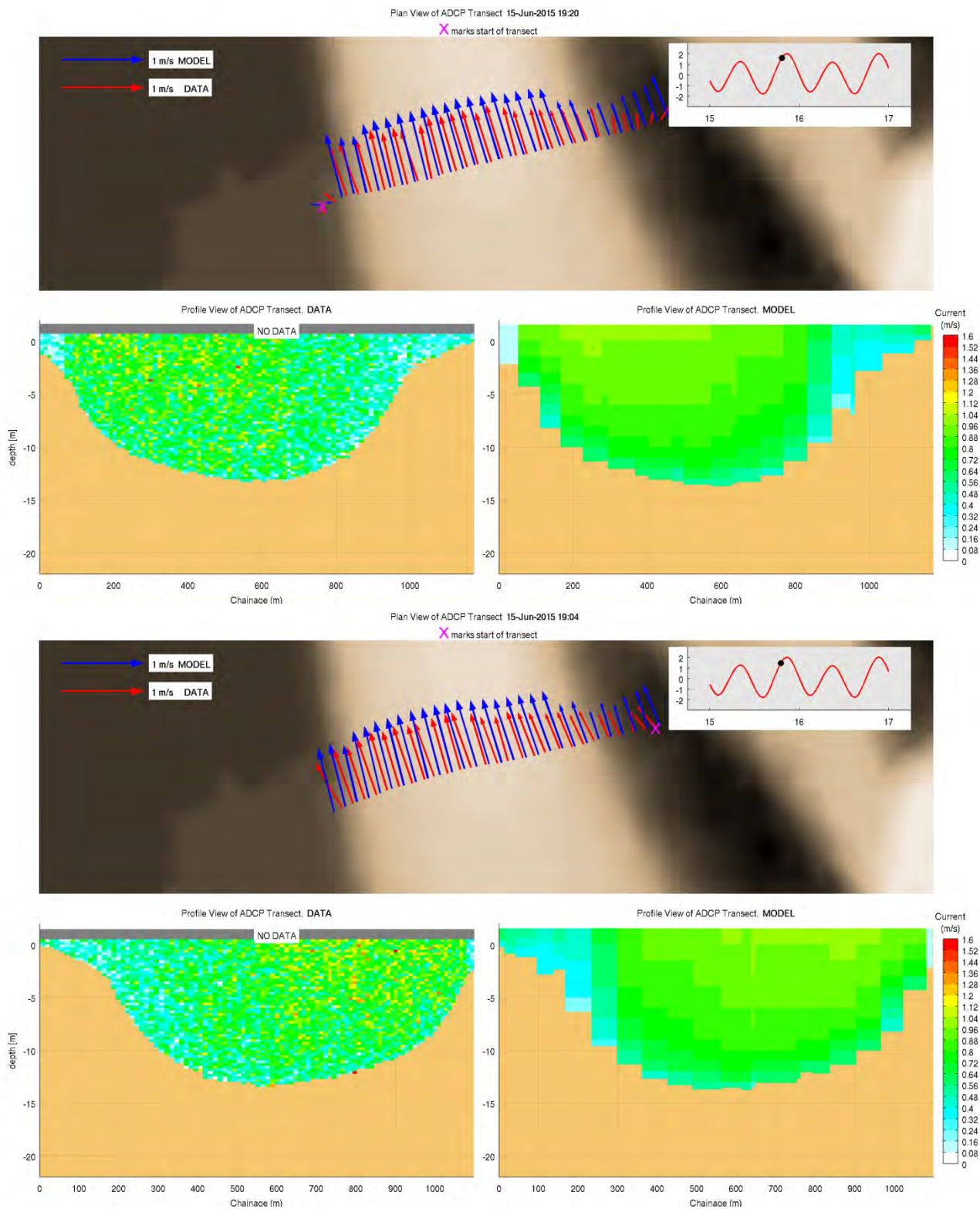


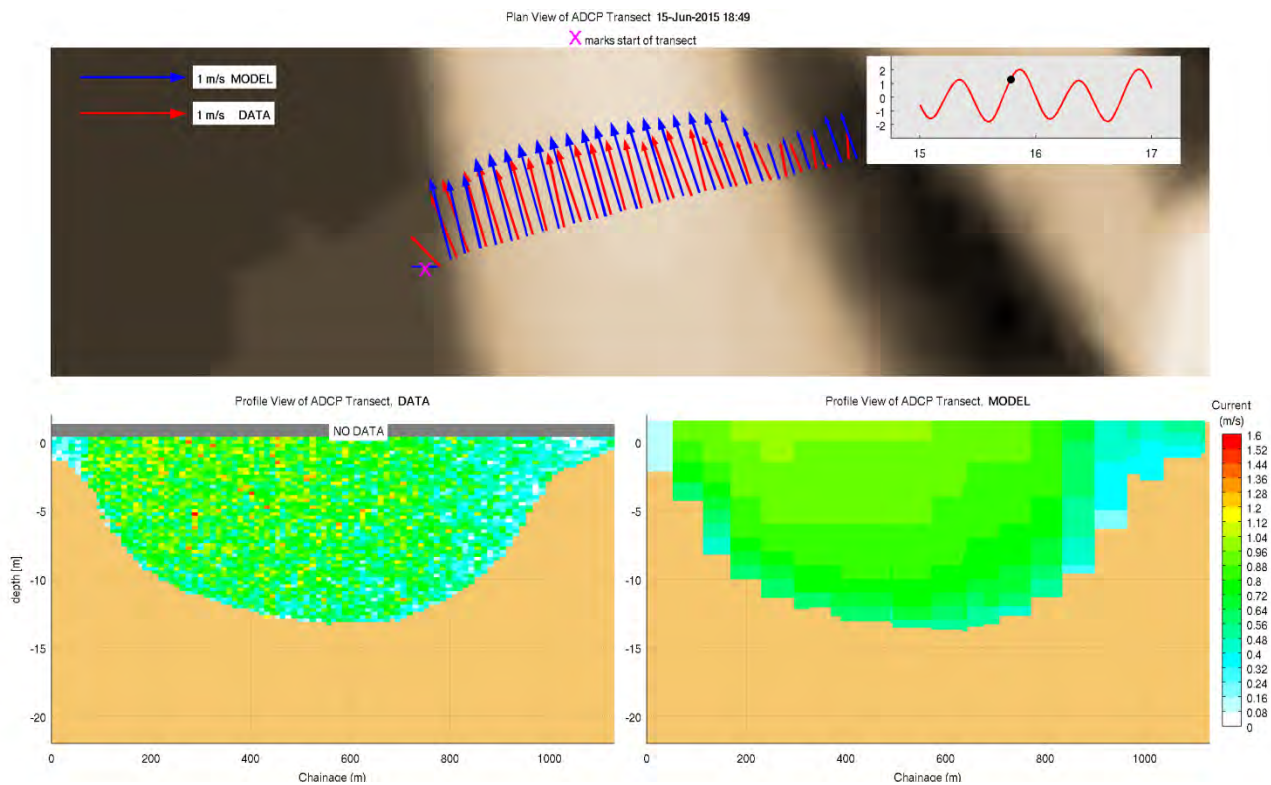




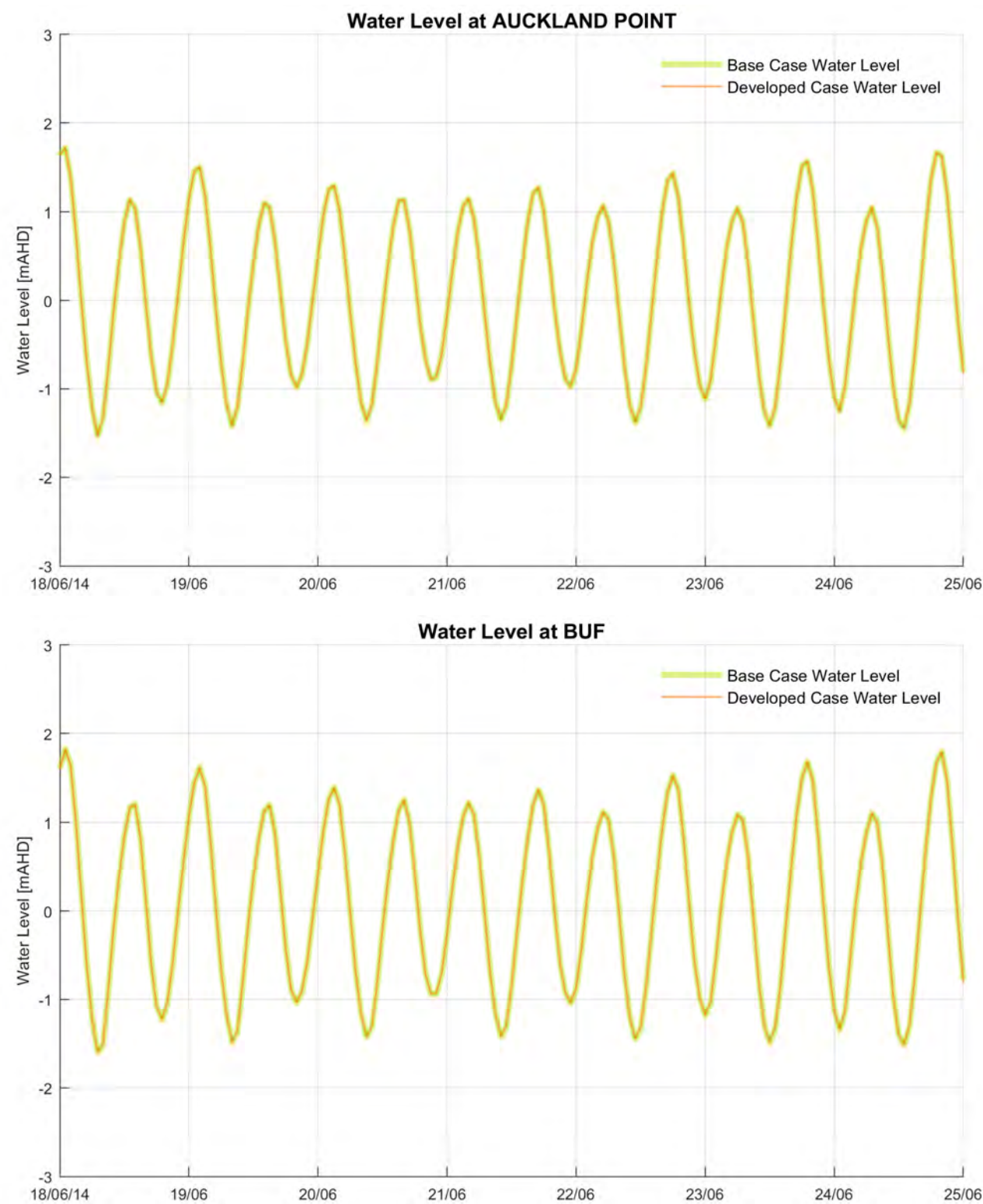


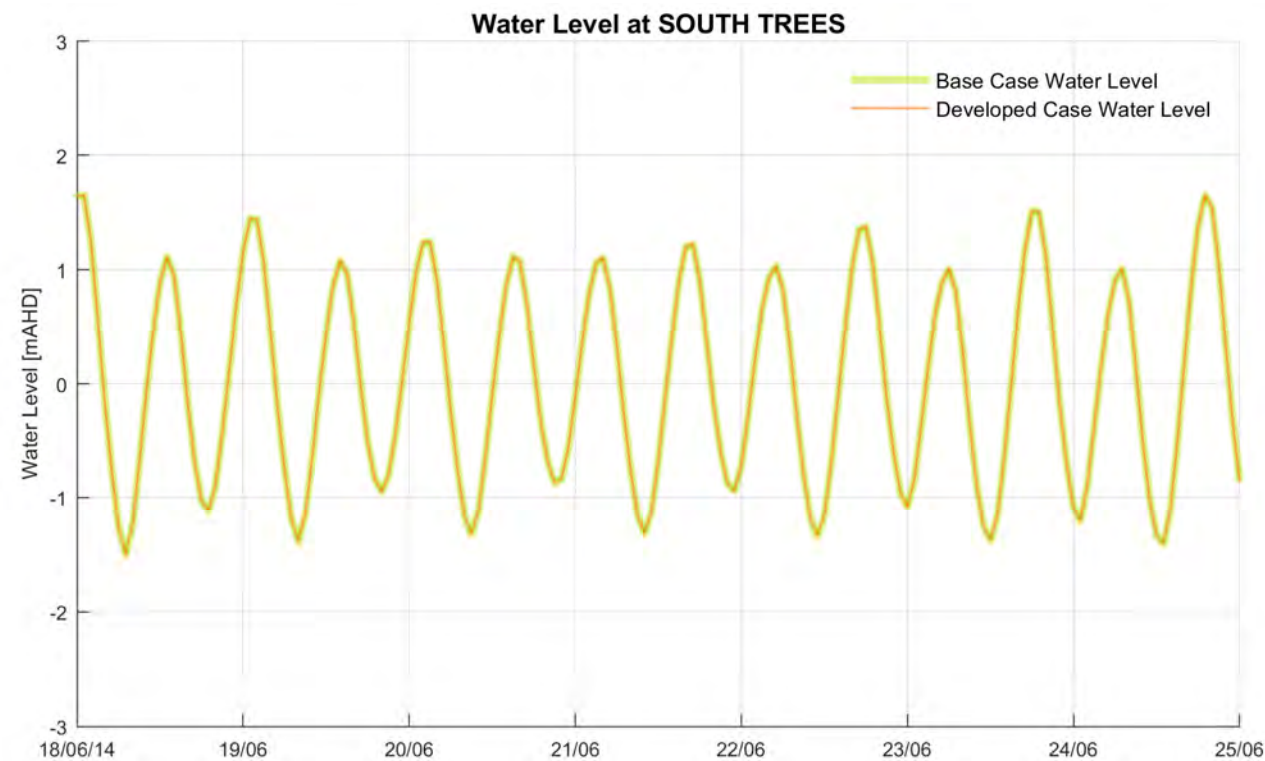
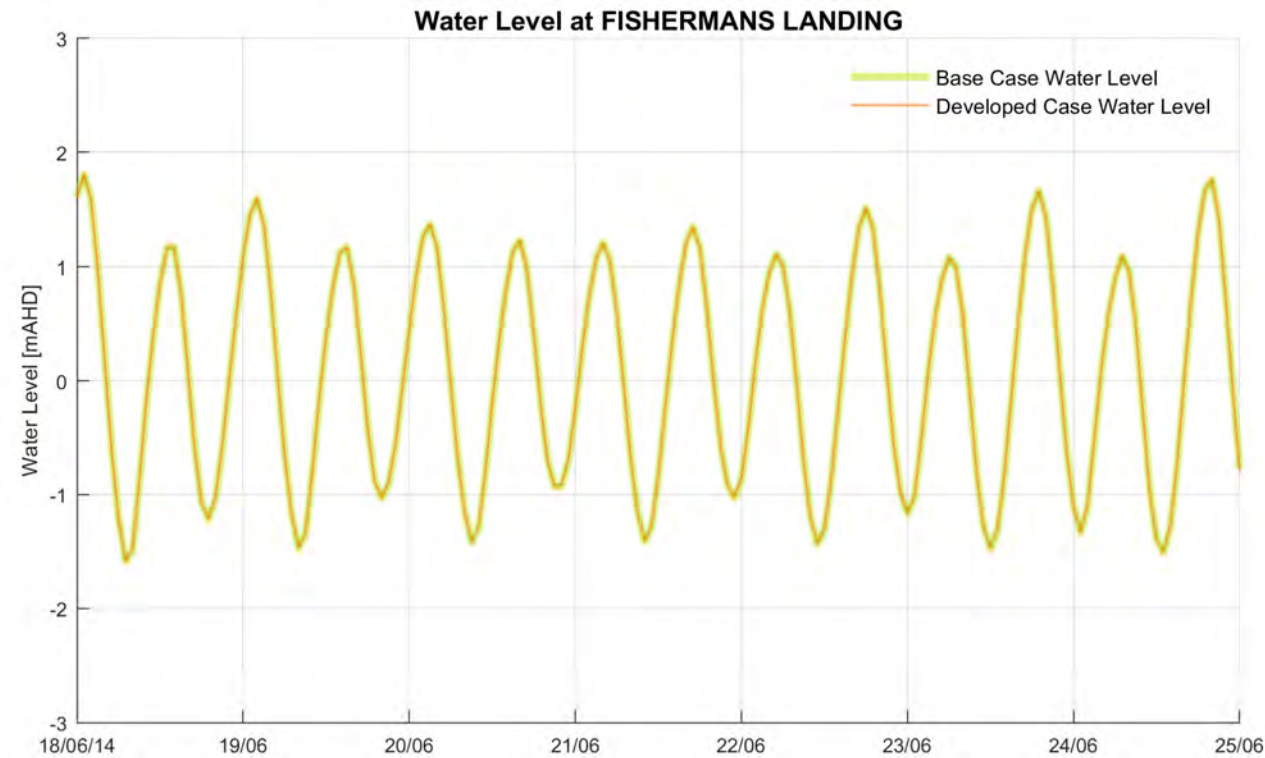




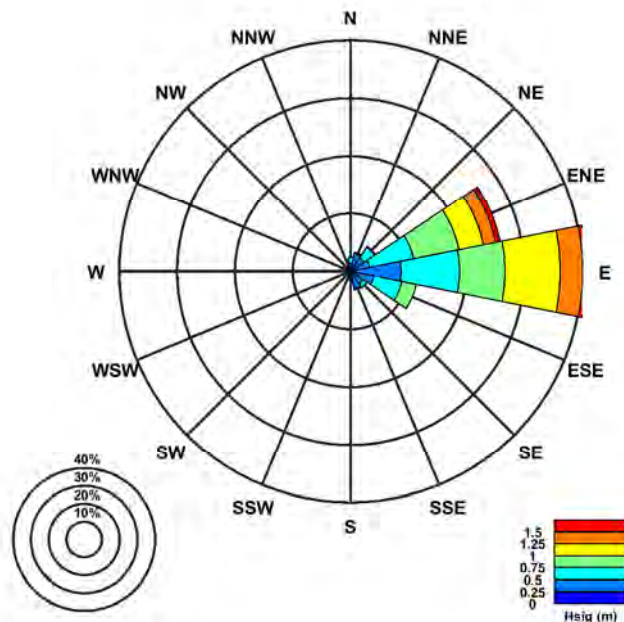
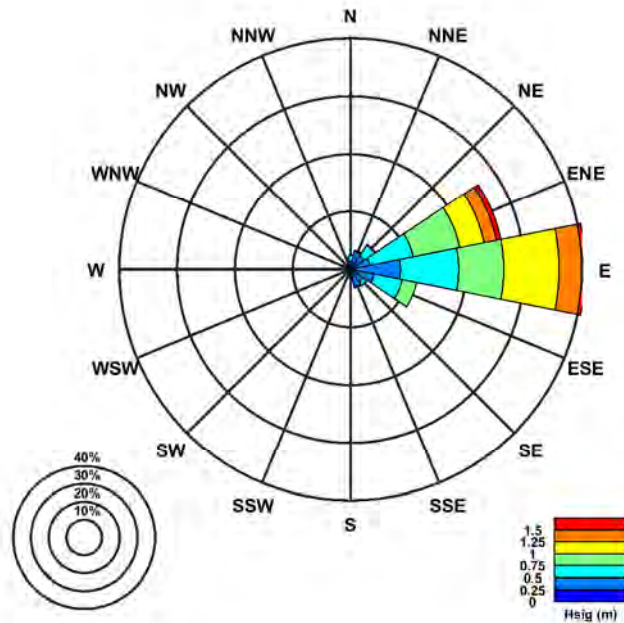


Appendix F Water Level Impact Plots

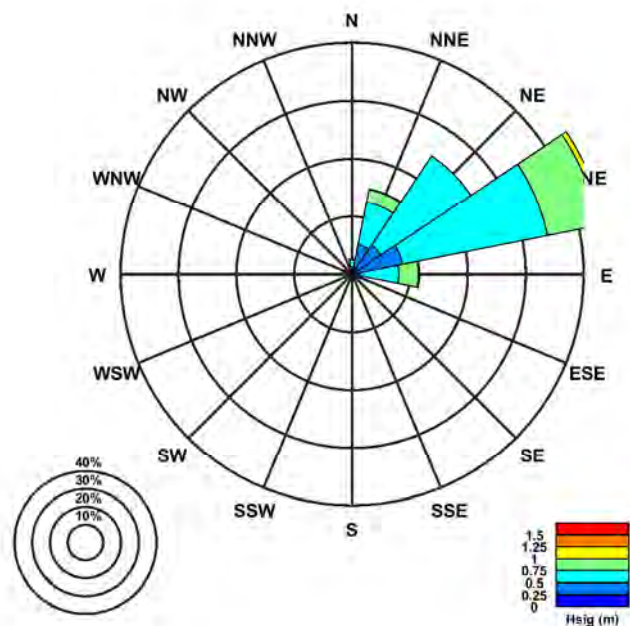
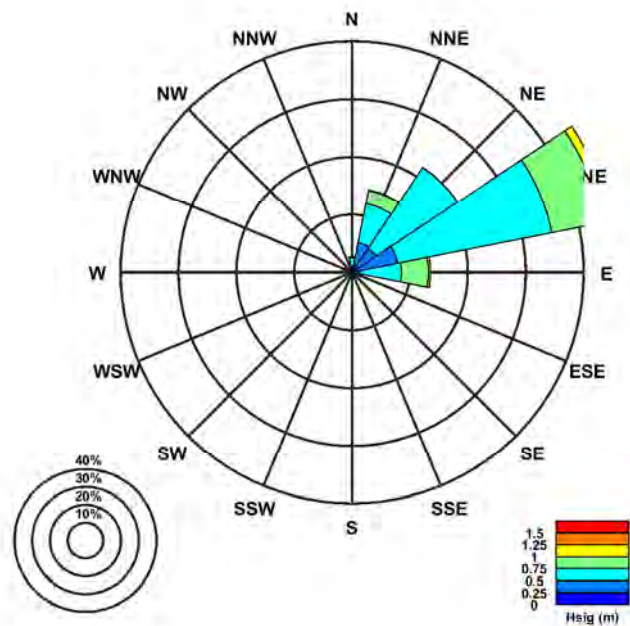




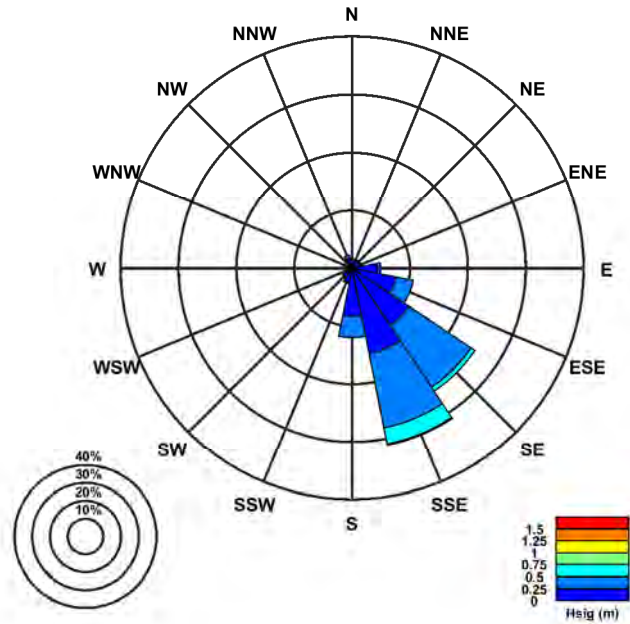
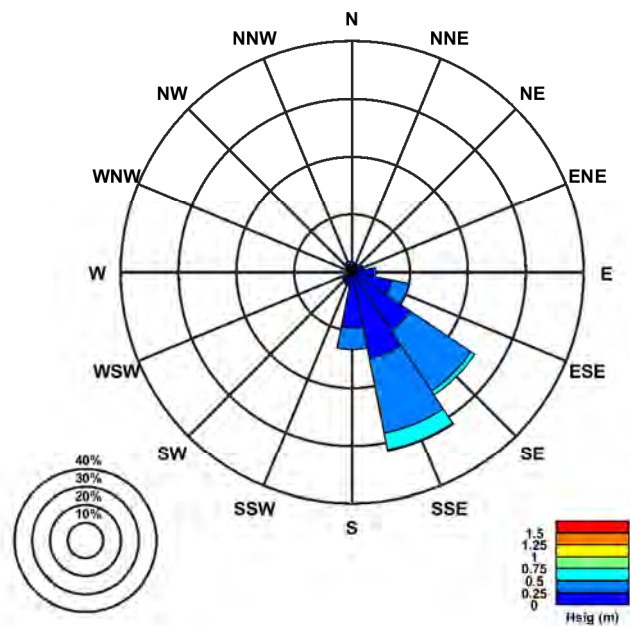
Appendix G Wave Rose Comparisons at ADCP Sites



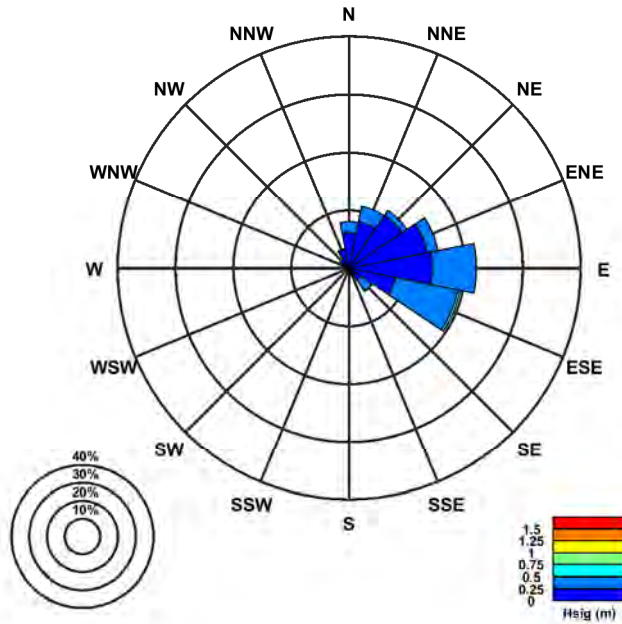
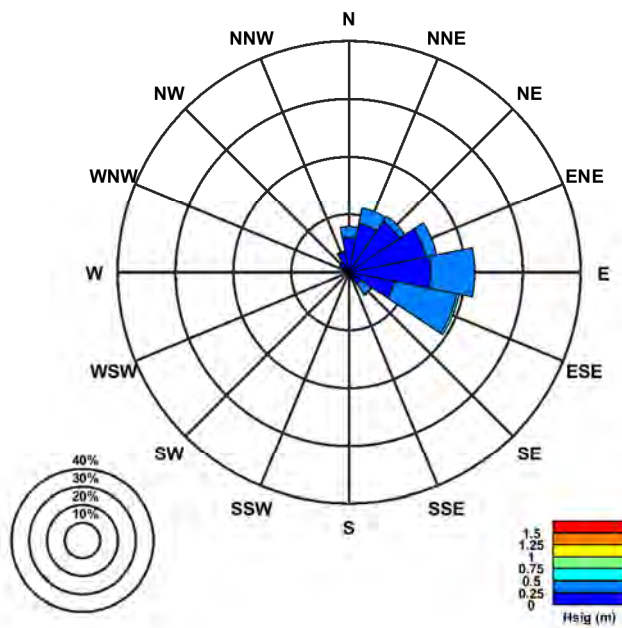
Wave Rose at ADCP 1 for the Base Case (Top) and
Project Channel Geometry Case (Bottom)



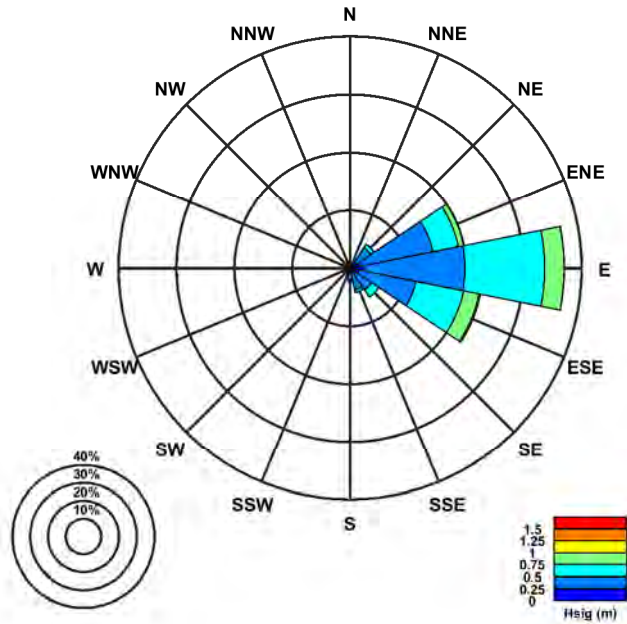
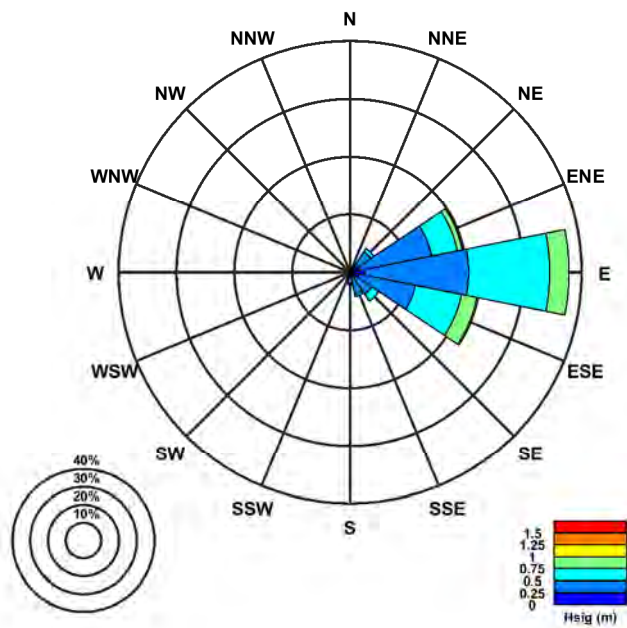
Wave Rose at ADCP 2 for the Base Case (Top) and Project Channel Geometry Case (Bottom)



Wave Rose at ADCP 3 for the Base Case (Top) and Project Channel Geometry Case (Bottom)



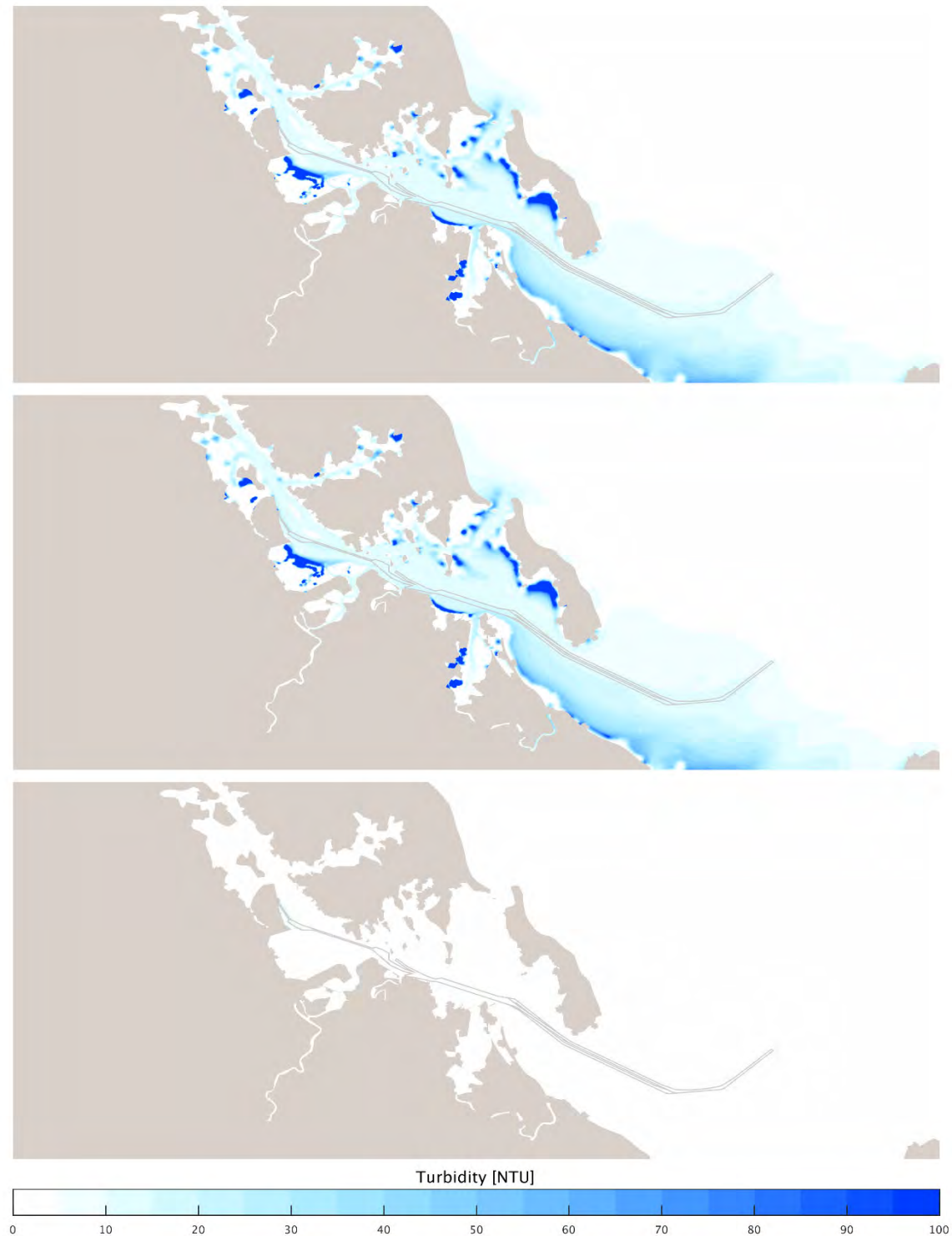
Wave Rose at ADCP 5 for the Base Case (Top) and
 Project Channel Geometry Case (Bottom)



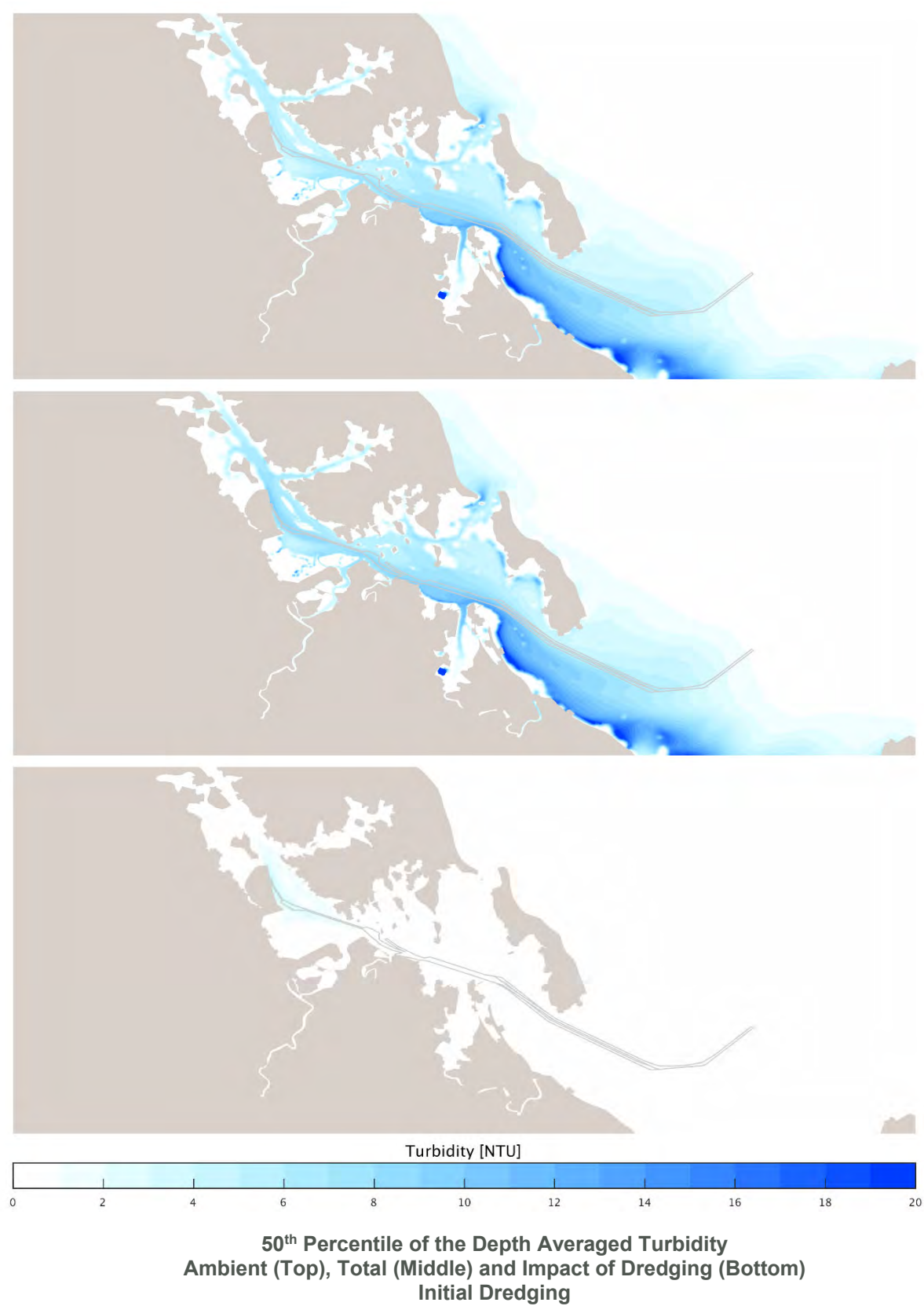
Wave Rose at ADCP 6 for the Base Case (Top) and
 Project Channel Geometry Case (Bottom)

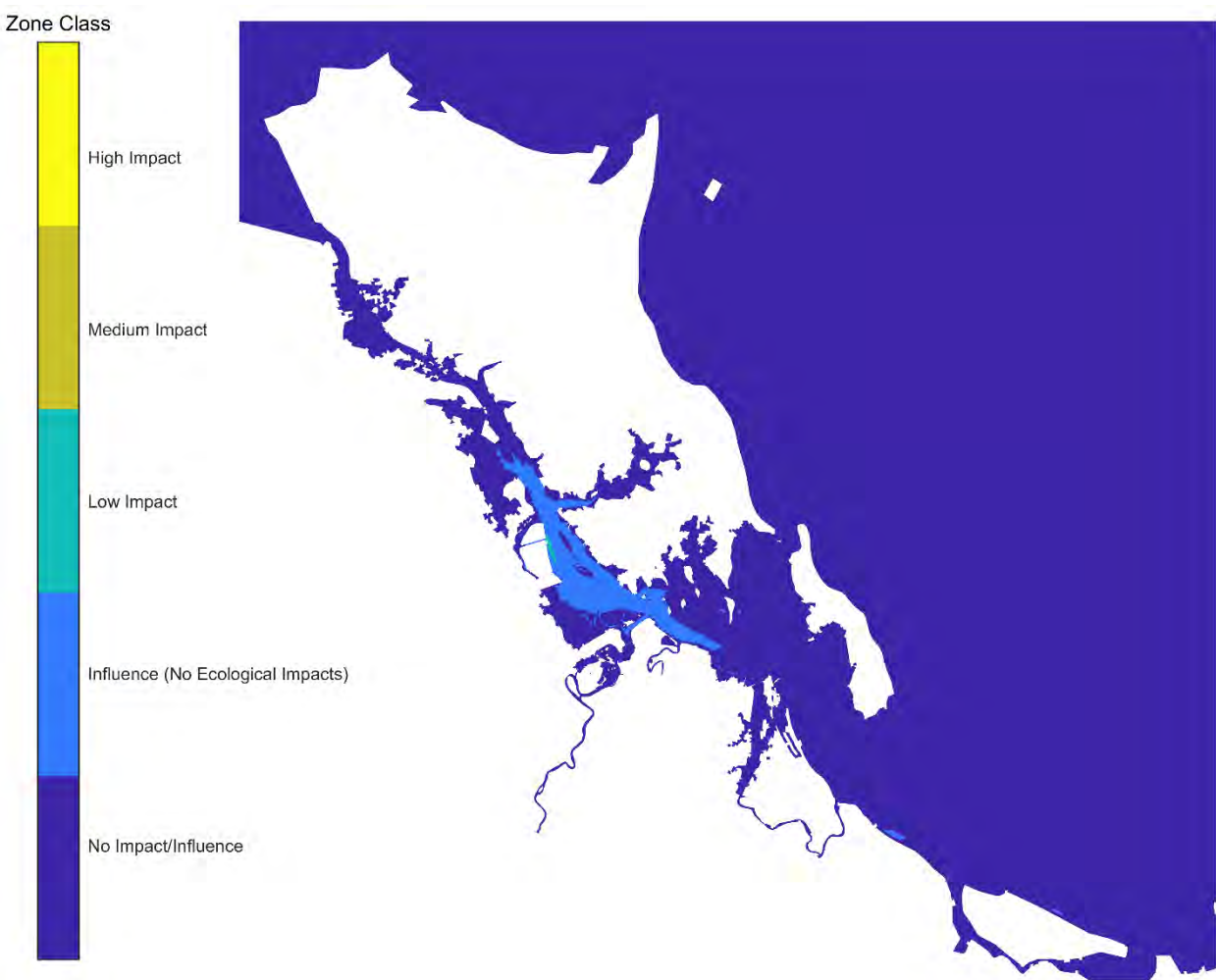
Appendix H Spatial Impact Plots for Each Stage of Dredging

Initial Dredging

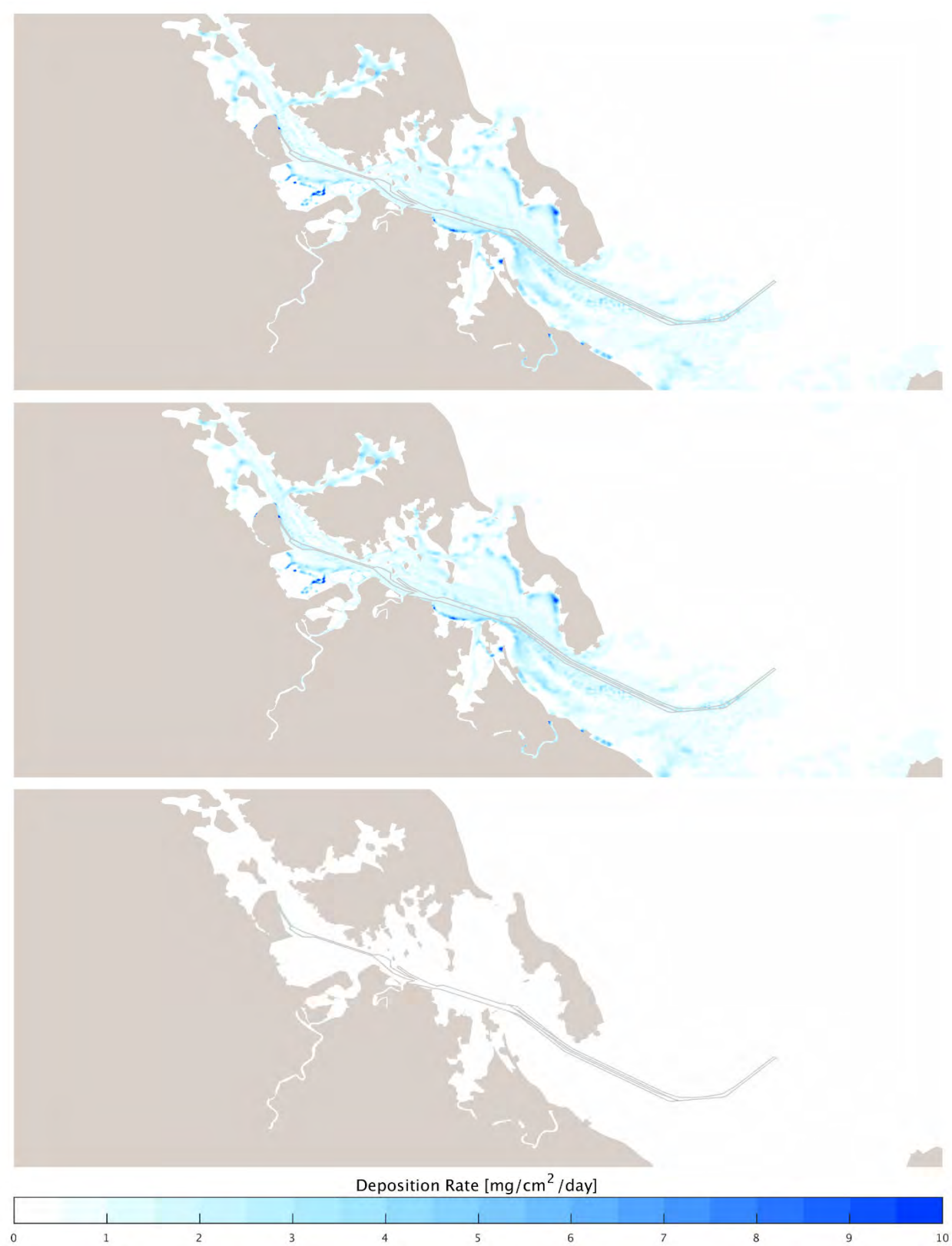


**95th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Initial Dredging**





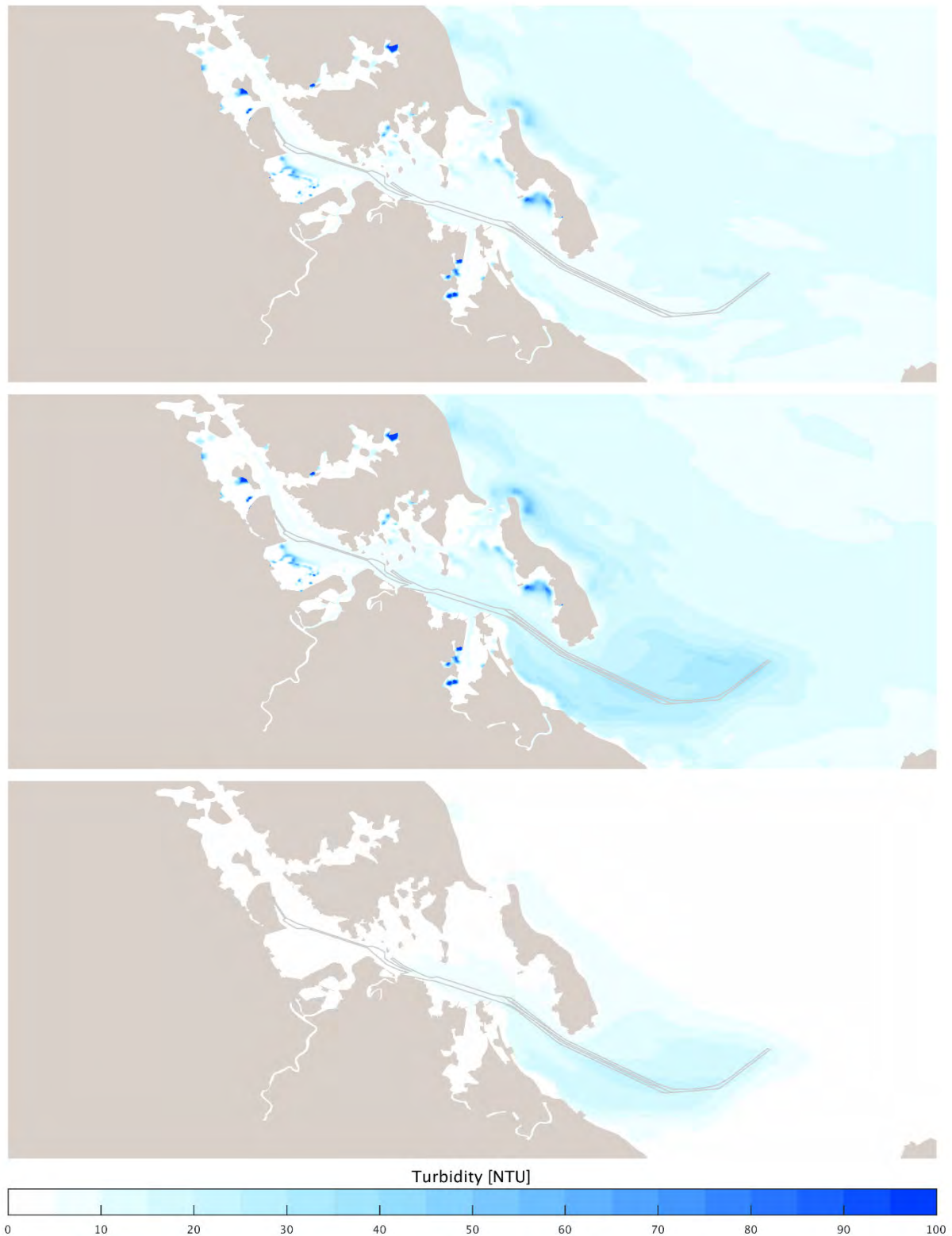
Zones of Impact for Initial Dredging



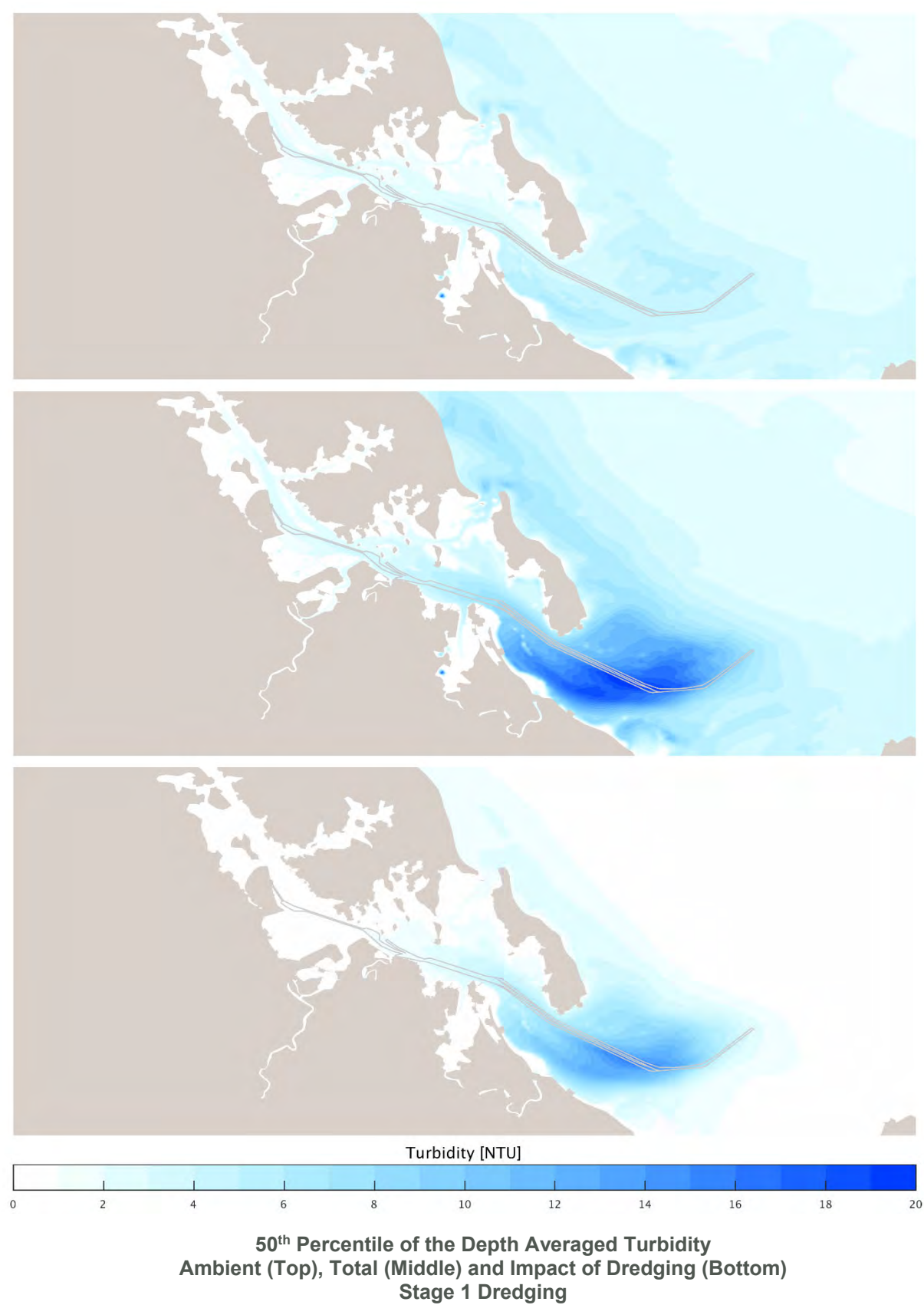
**95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Initial Dredging**

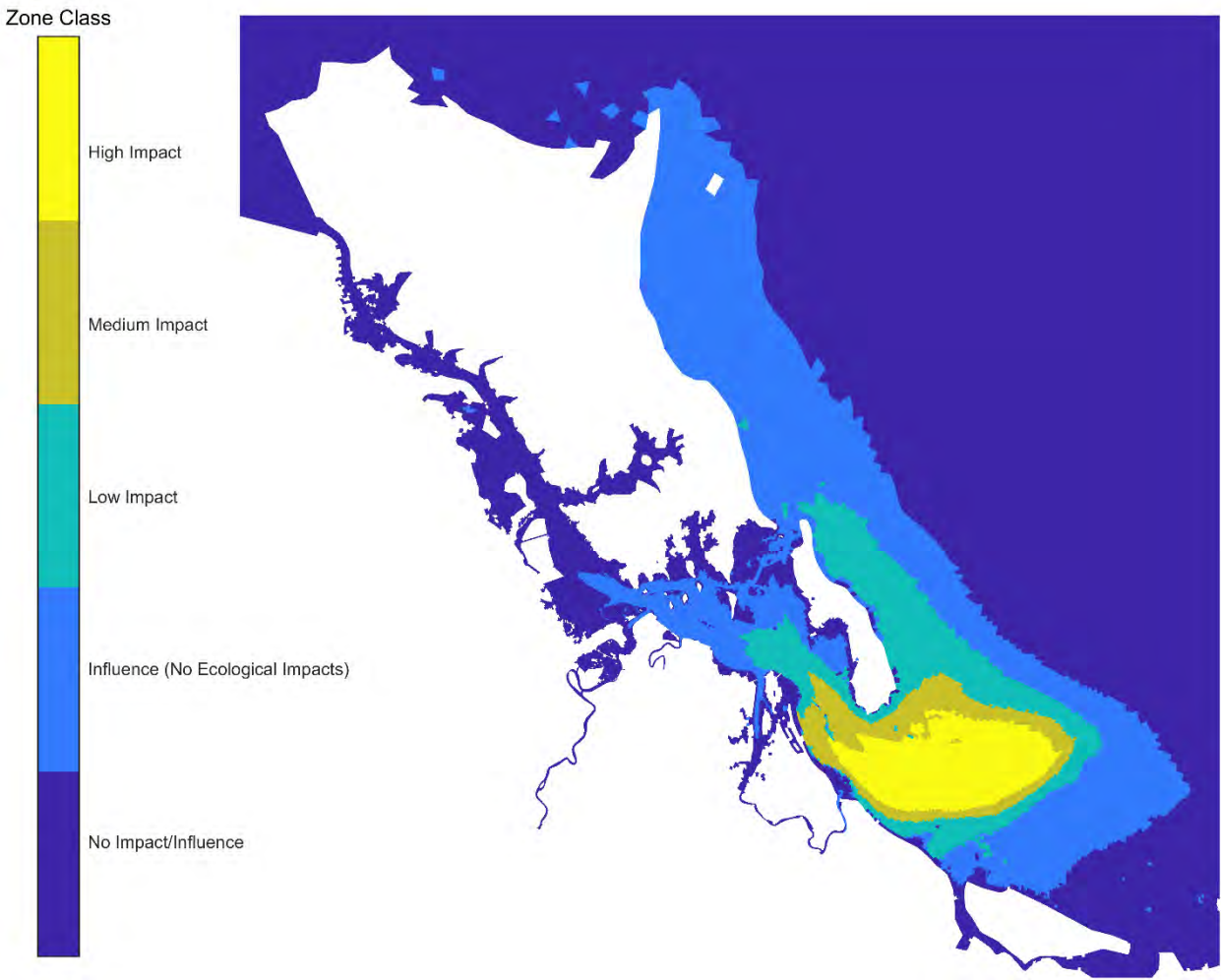


Stage 1 Dredging



**95th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Stage 1 Dredging**





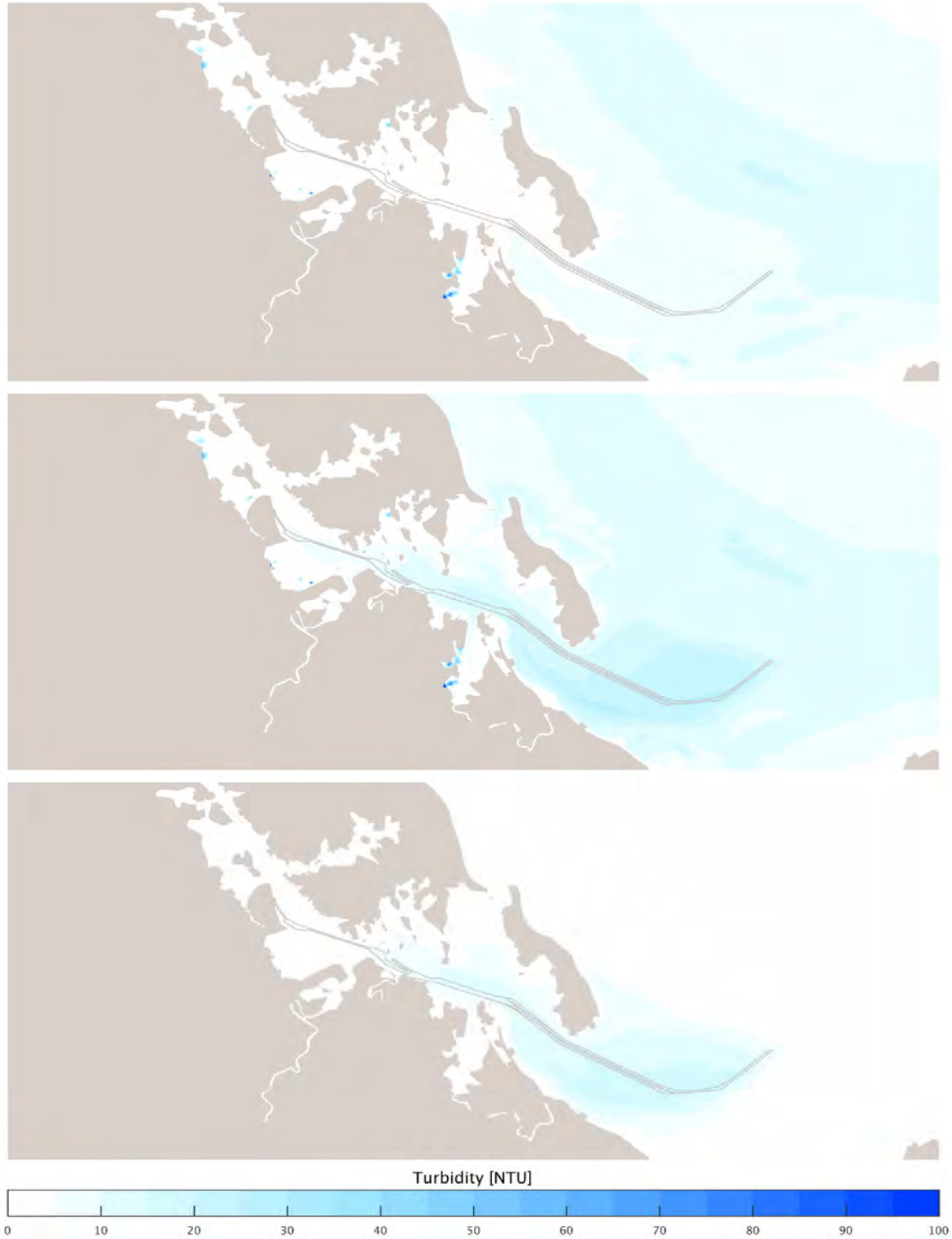
Zones of Impact for Stage 1 Dredging



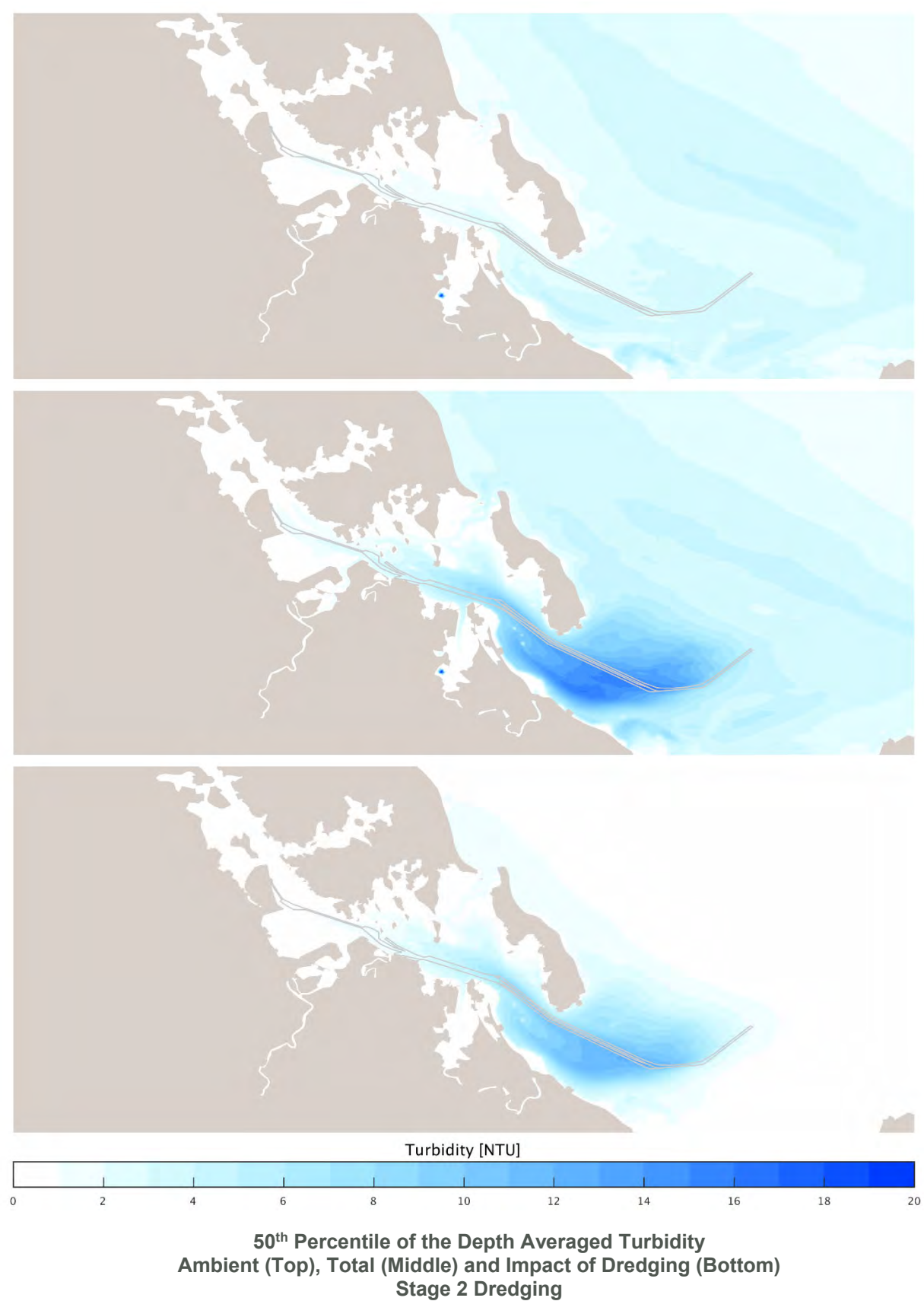
95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Stage 1 Dredging

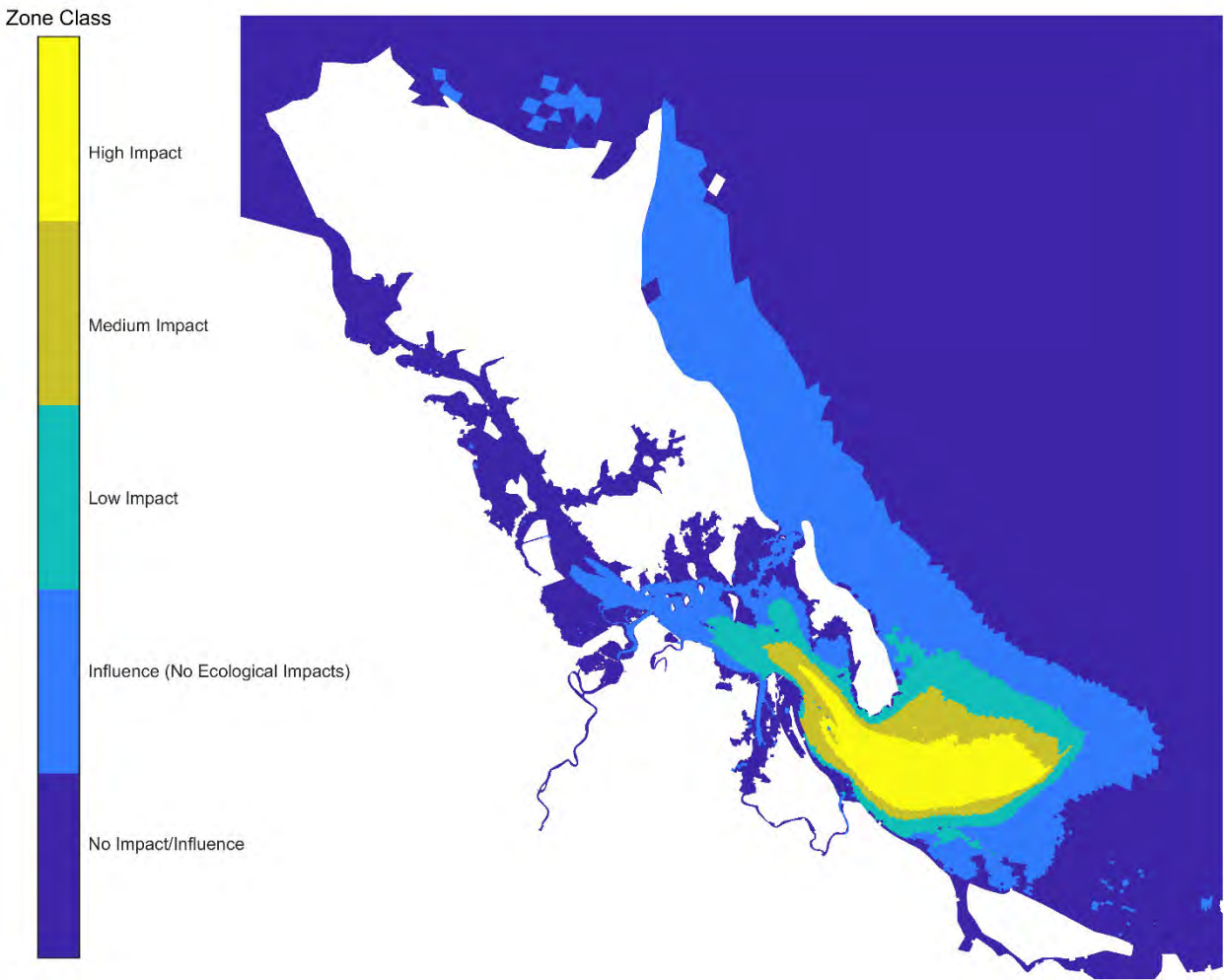


Stage 2 Dredging



**95th Percentile of the Depth Averaged Turbidity
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Stage 2 Dredging**





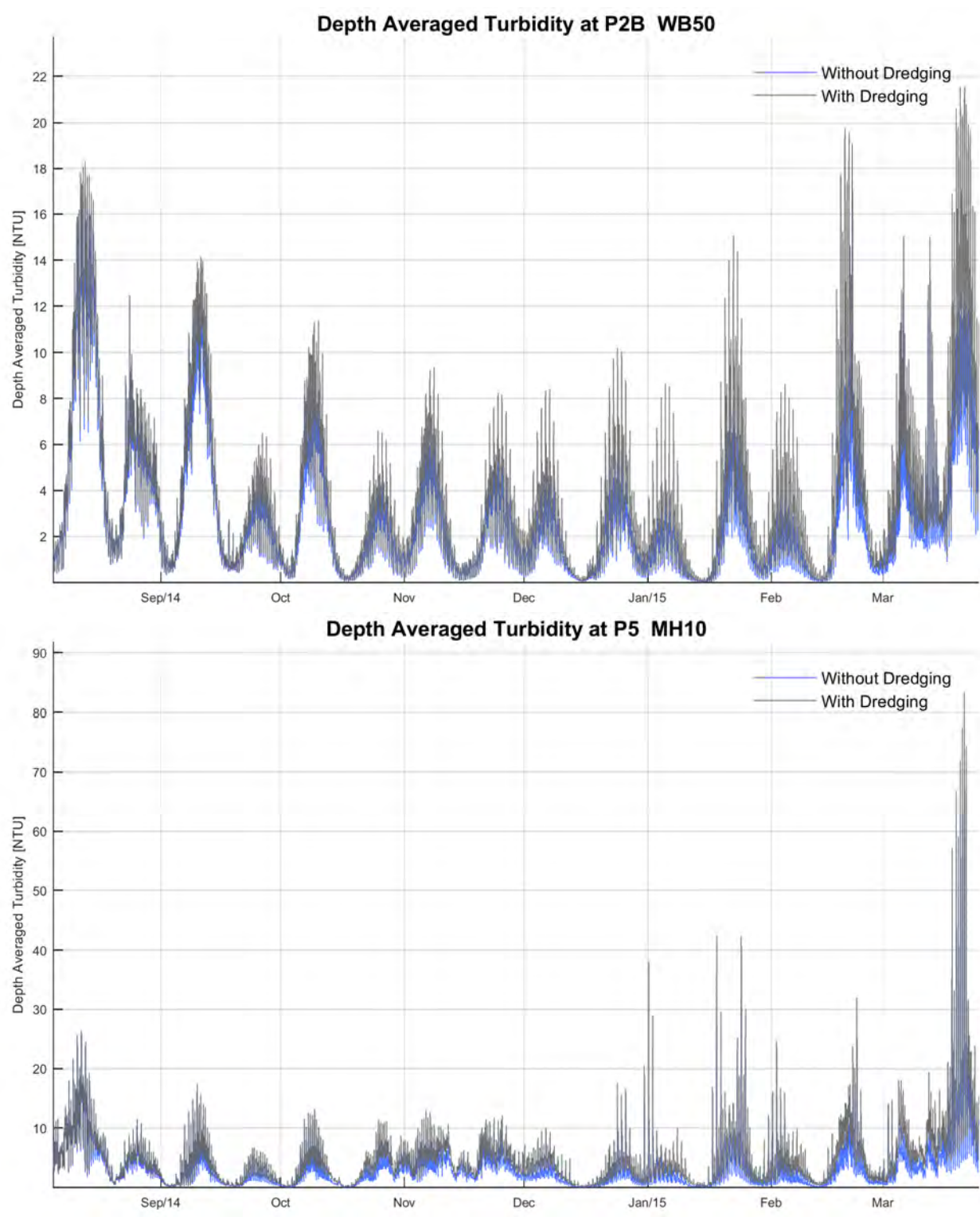
Zones of Impact for Stage 2 Dredging

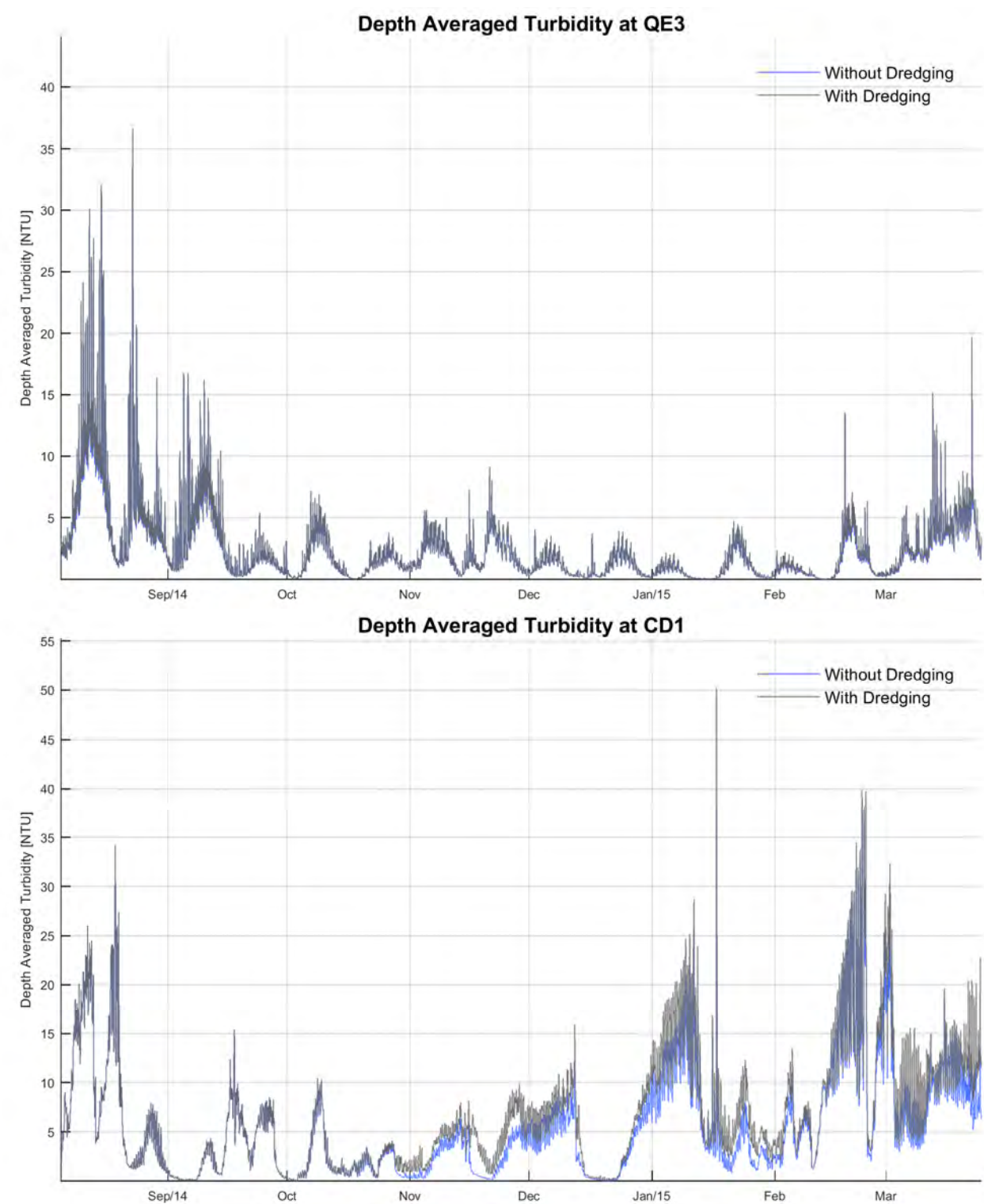


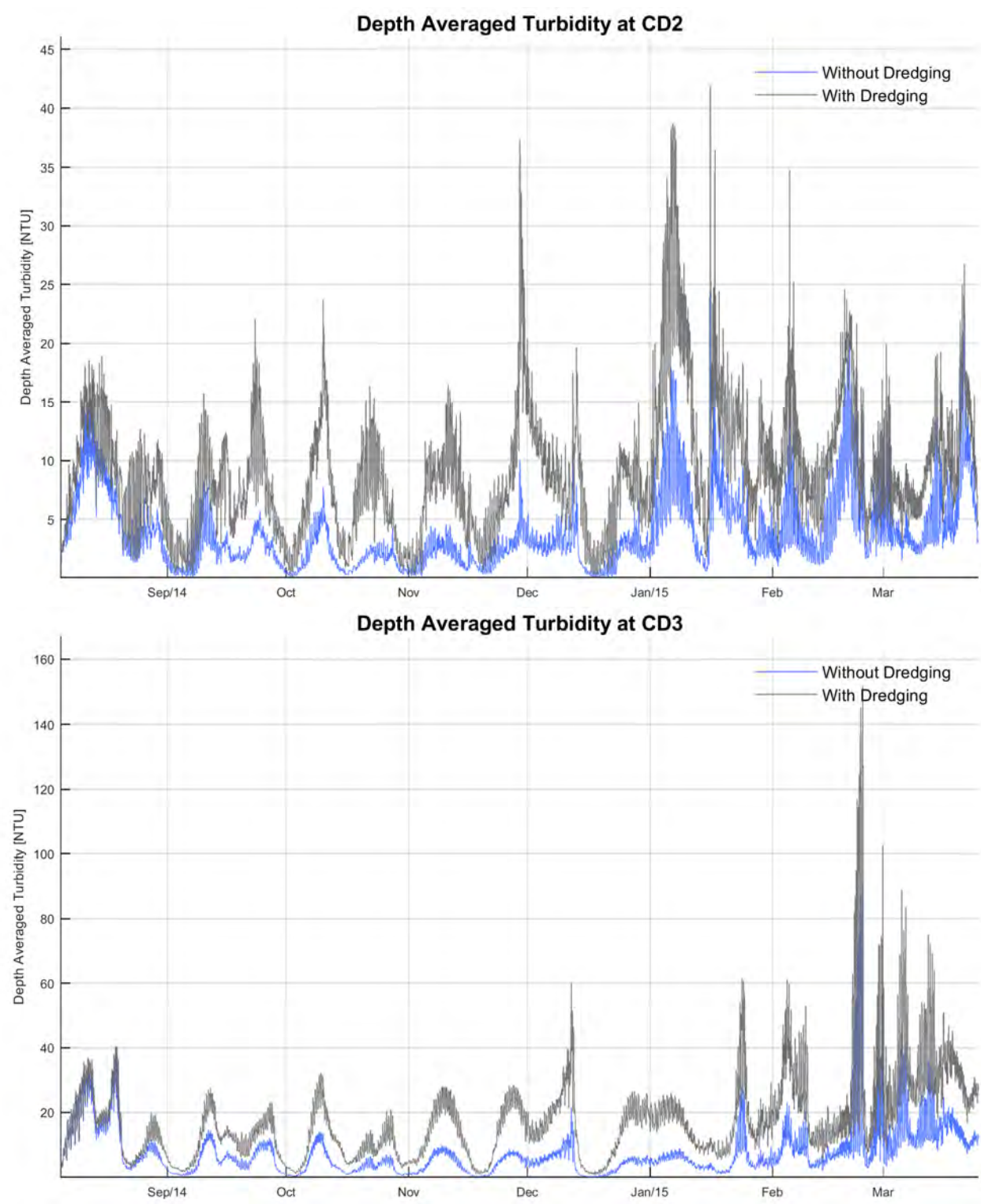
**95th Percentile of the Deposition Rate
Ambient (Top), Total (Middle) and Impact of Dredging (Bottom)
Stage 2 Dredging**

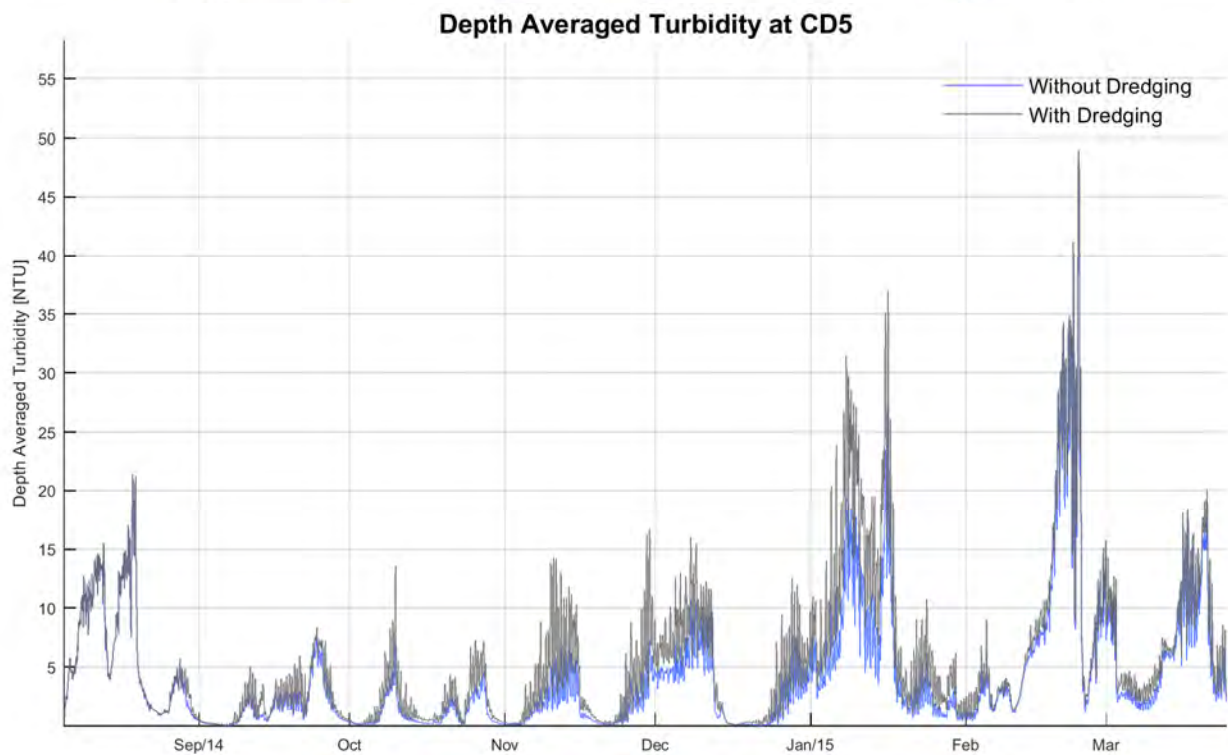
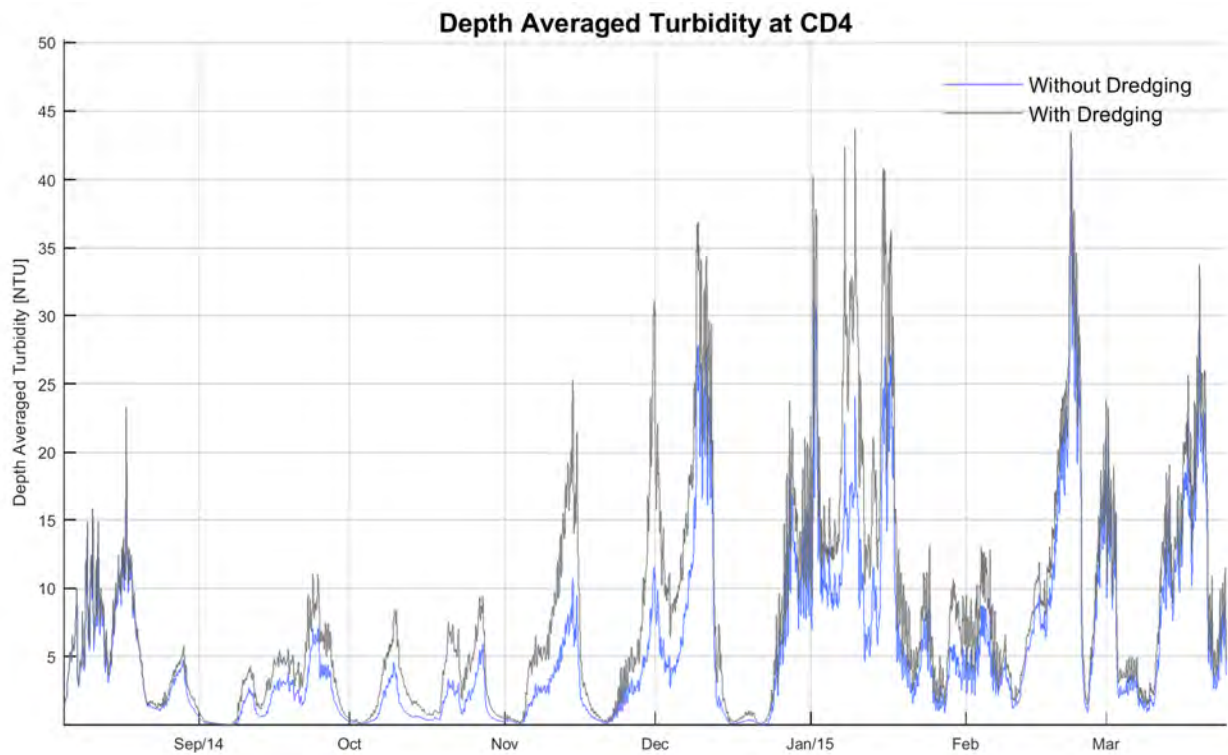


Appendix I Time Series of Depth Averaged Turbidity

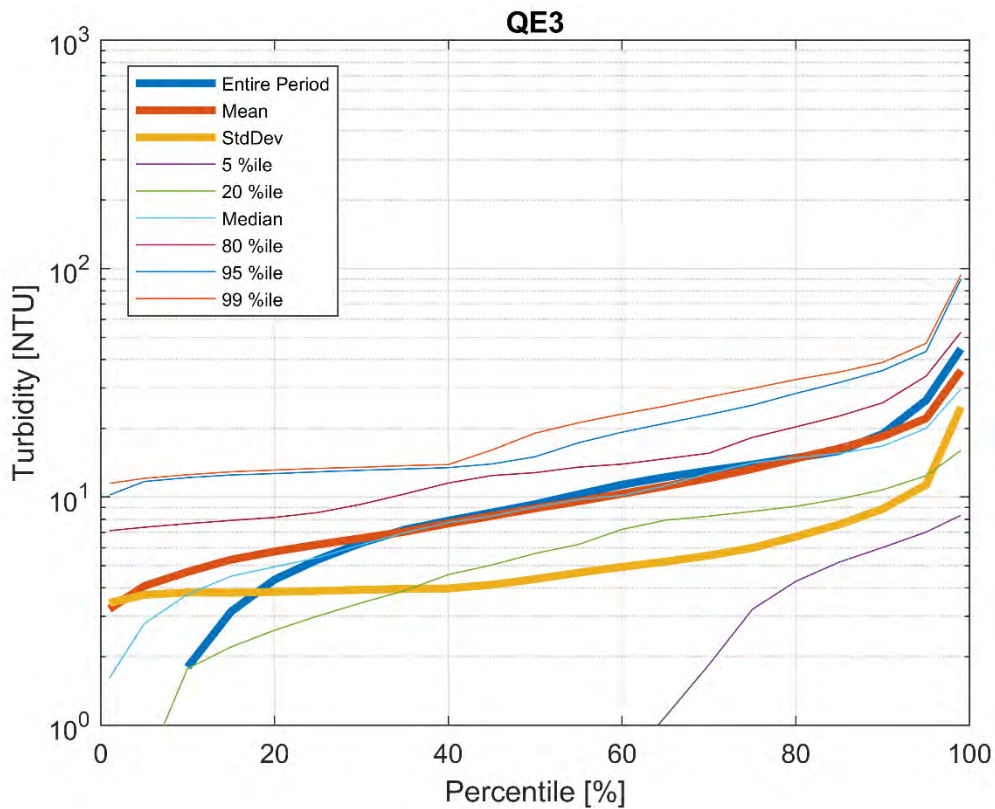
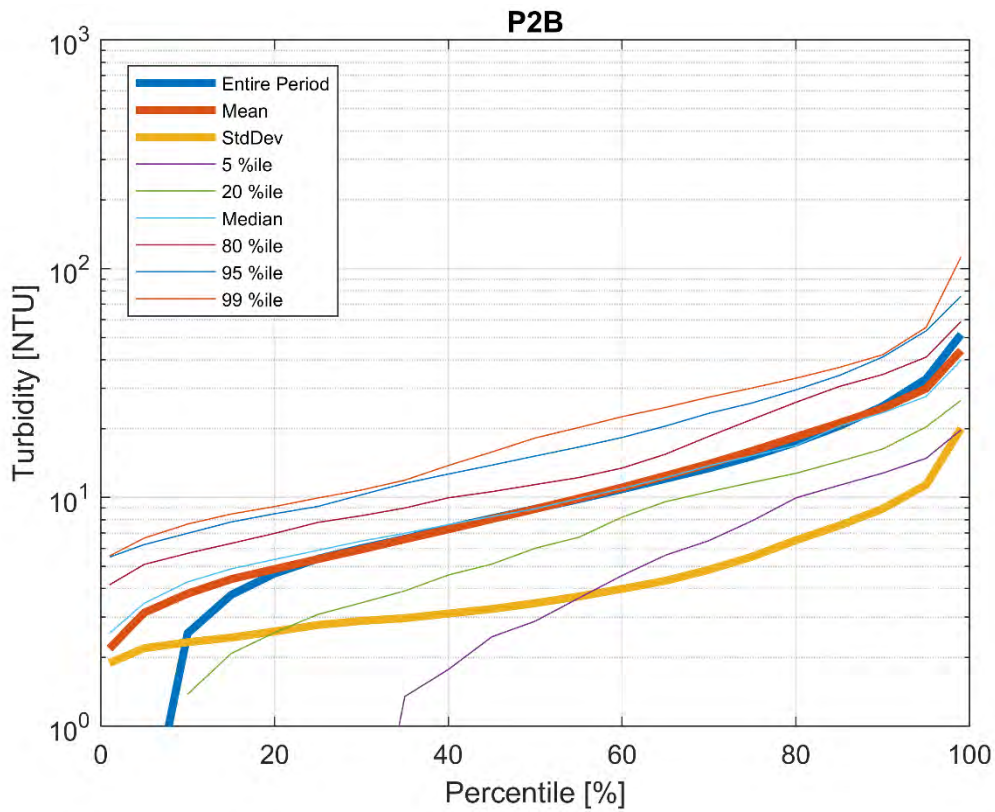


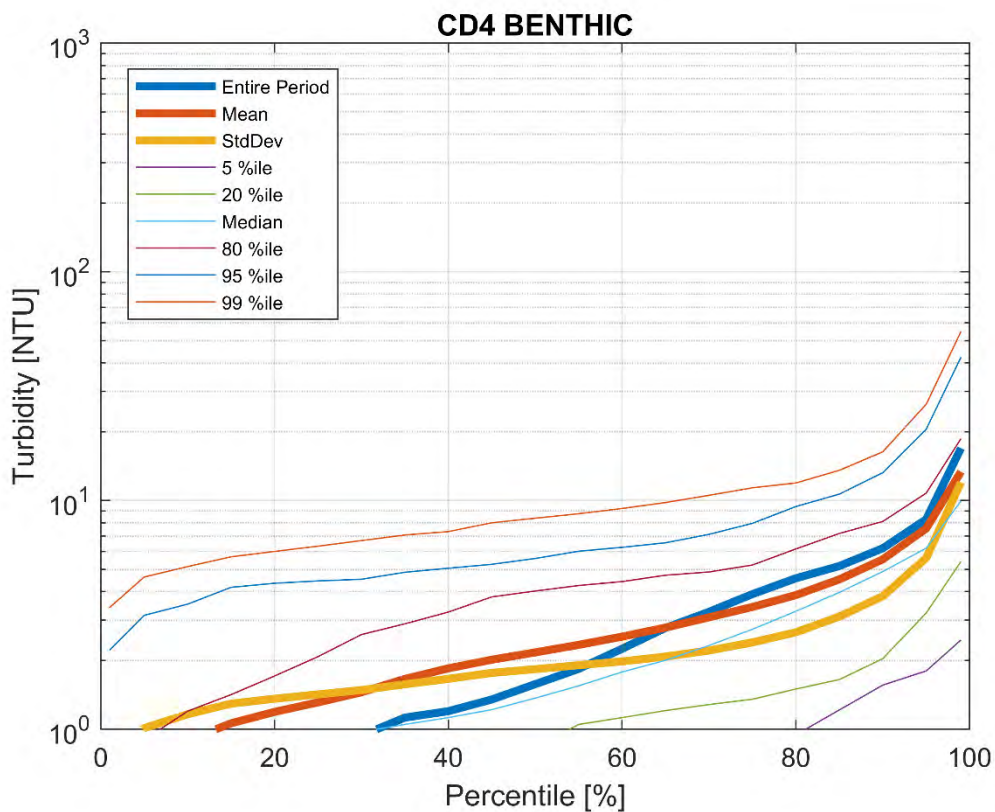
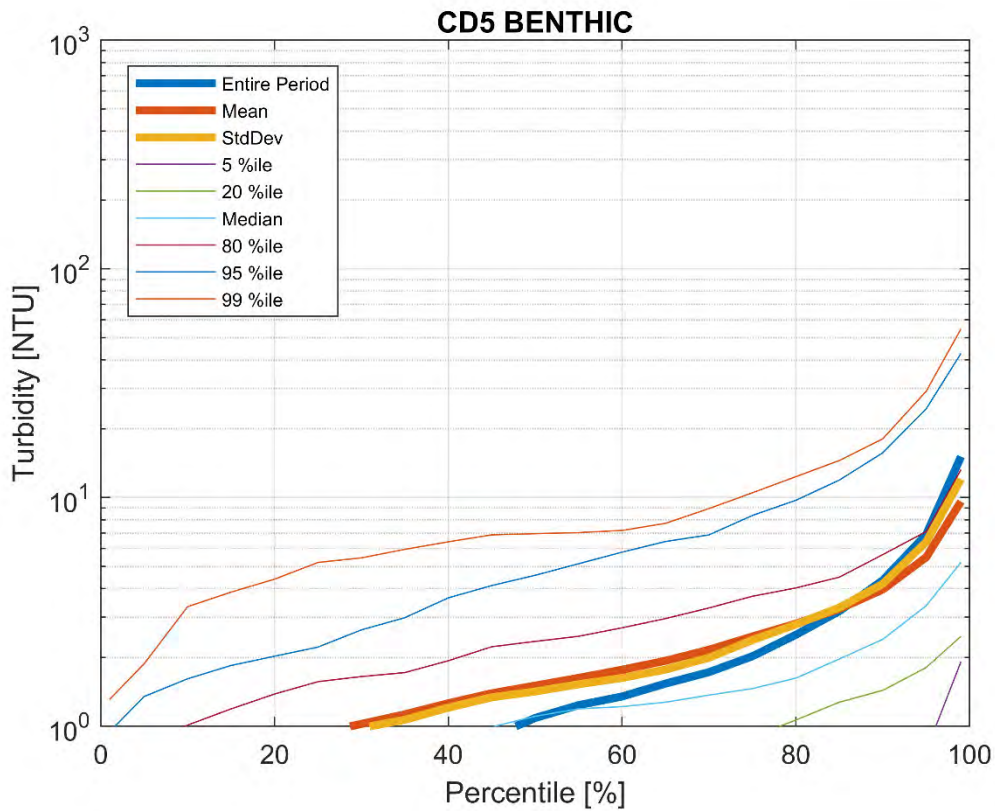


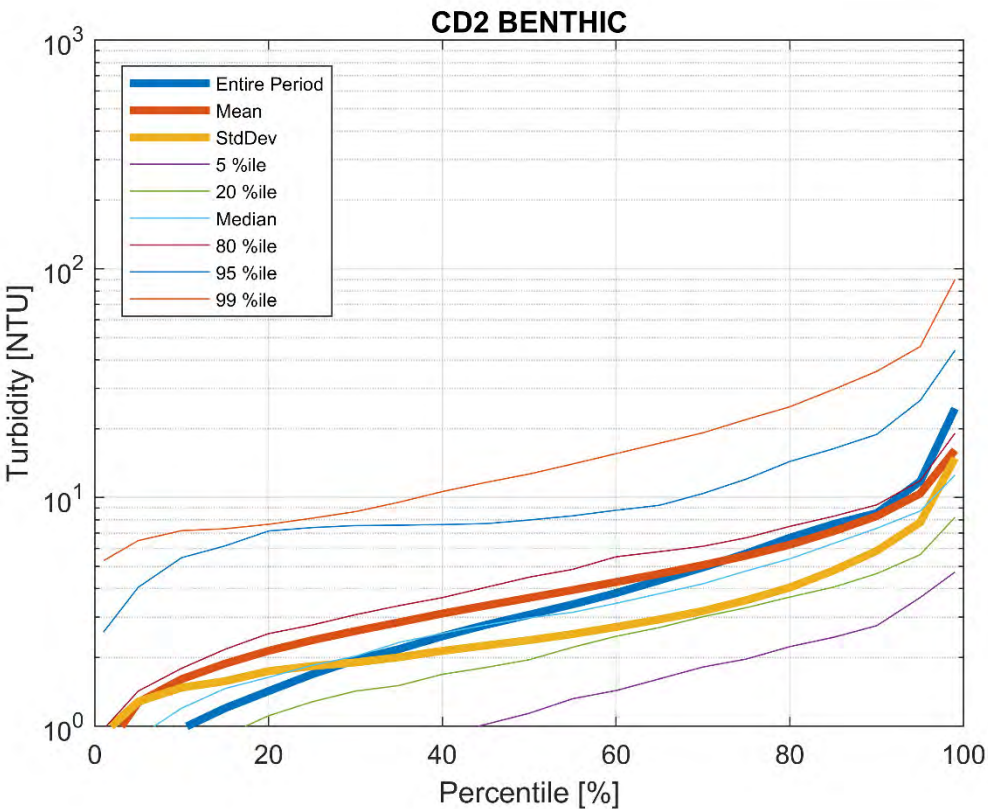
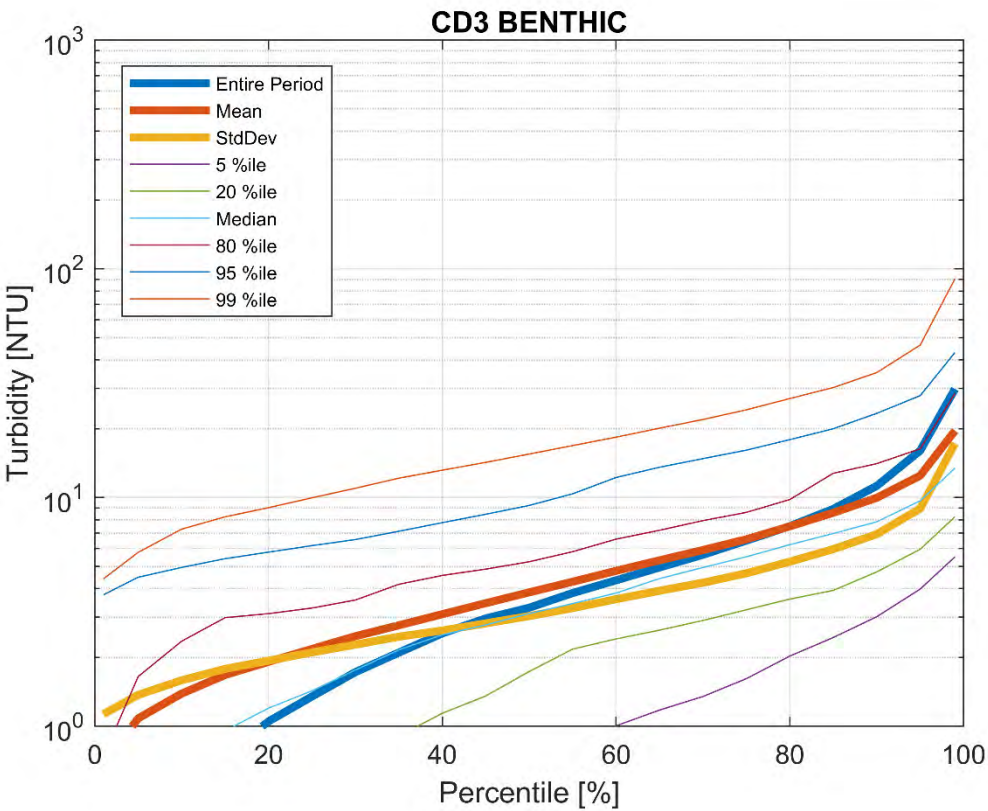


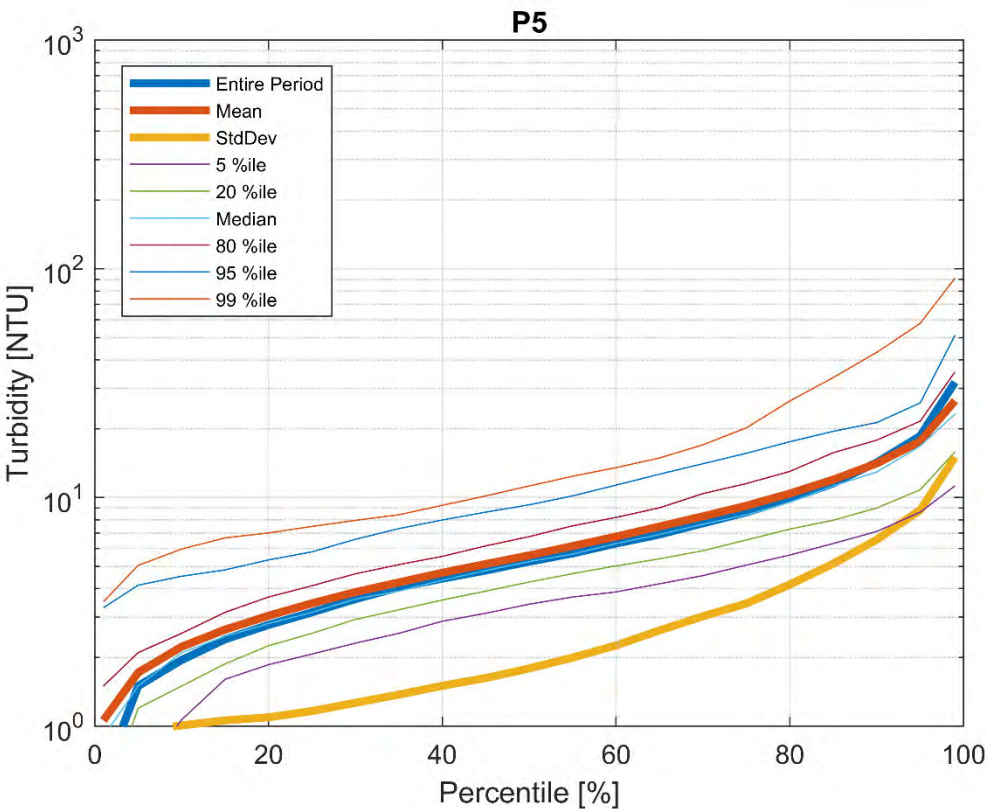
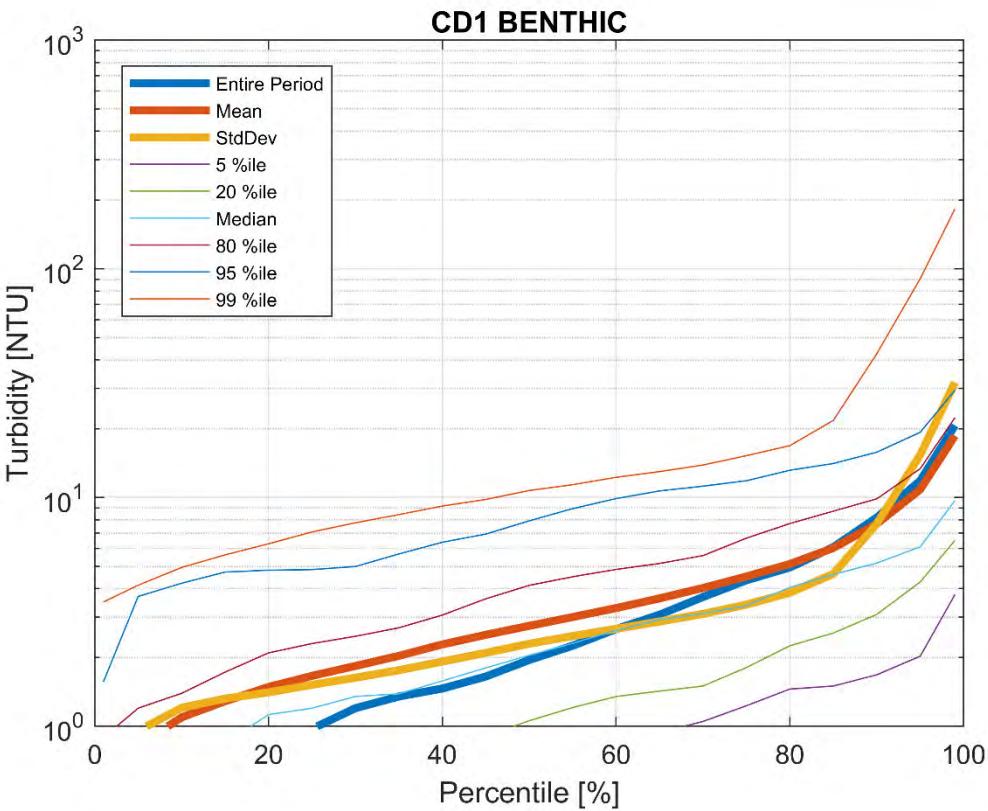


Appendix J Measured Ambient Turbidity Percentiles









Appendix K Peer Review Report

Our Ref 59914128/L006

Contact P.D. Treloar



19 February 2019

Aurecon
32 Turbot Street
BRISBANE QLD 4001

Cardno (NSW/ACT) Pty Ltd
ABN 95 001 145 035

Attention: Mr Bruce Penman, Technical Director - Environment & Planning

Level 9, The Forum
203 Pacific Highway
St Leonards New South Wales 2065
PO Box 19
St Leonards New South Wales 1590
Australia

Dear Sir,

**PORT OF GLADSTONE CHANNEL DUPLICATION EIS
HYDRODYNAMIC MODELLING - INDEPENDENT PEER REVIEW**

Telephone: 02 9496 7700
Facsimile: 02 9439 5170
International: +61 2 9496 7700

I have completed my independent peer review of the BMT WBM Channel Duplication Coastal Processes and Hydrodynamics data collection, modelling establishment and validation tasks, followed by preparation of their Technical Report, and confirm the following:

Web: www.cardno.com.au

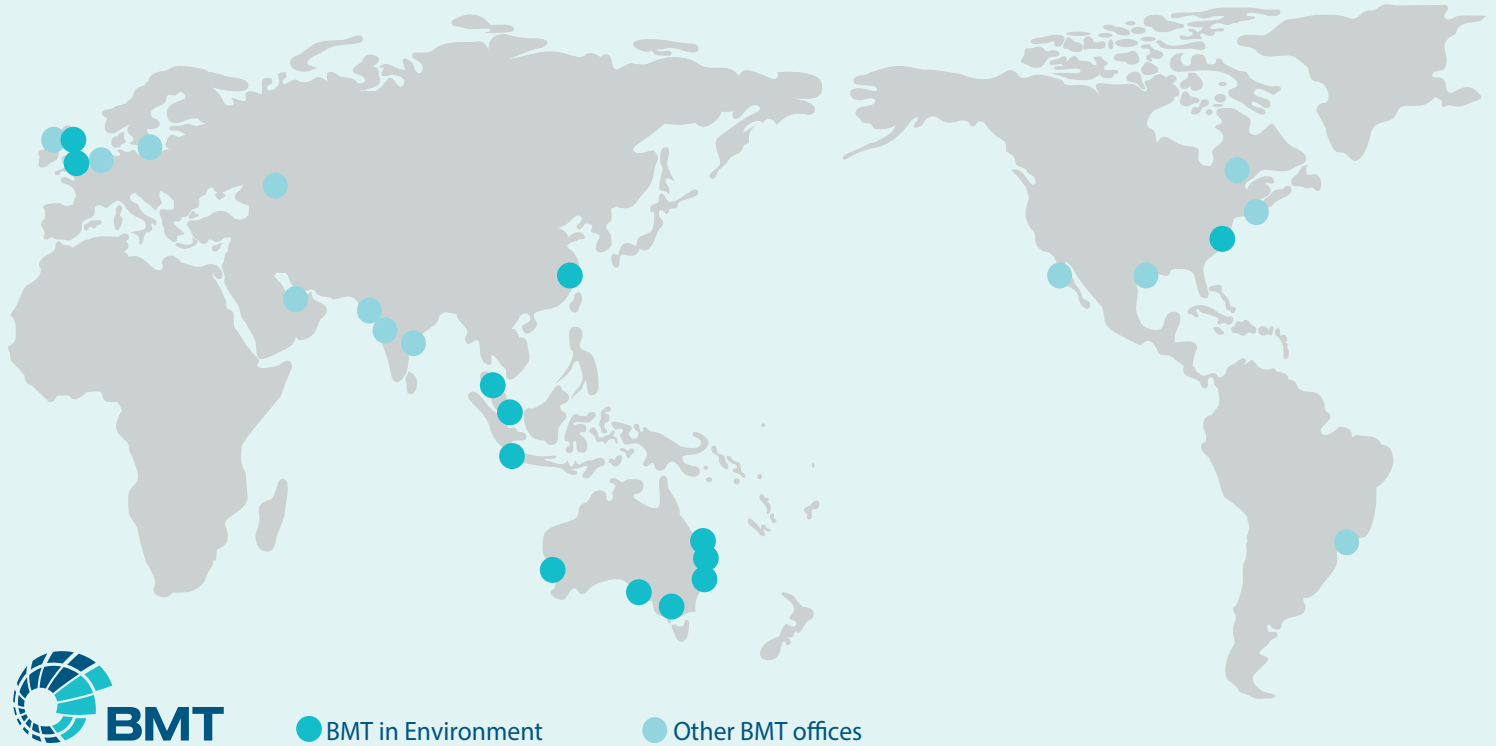
- I was involved in the review of the modelling data collection plan, and advise that the data collection program was appropriate for developing an accurate and robust model for hydrodynamic modelling undertaken for the proposed Gladstone Channel Duplication Project EIS. It is noted also that the Great Barrier Reef Marine Park Authority has also confirmed the suitability of the data collection work for this project.
- I was involved in establishing the model validation procedures and confirm that the model established for the Project was appropriate for accurately predicting the impacts of the Project in the marine environment.
- I was involved in the review of the Technical Reports, the draft Project Coastal Processes and Hydrodynamic Technical Reports, including the final Technical Report that is included in the Project EIS for public display, and confirm that the reports and findings were appropriate for documenting the findings of the modelling and the predicted impacts of the Project.

Yours faithfully,

P.D. Treloar
**Senior Principal – Coastal Engineering
for Cardno (NSW/ACT) Pty Ltd**

BMT has a proven record in addressing today's engineering and environmental issues.

Our dedication to developing innovative approaches and solutions enhances our ability to meet our client's most challenging needs.



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